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Current Measurements from Moored Buoys

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Current Measurements from Moored Buoys

by

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CURRENT MEASUREMENTS FROM MOORED BUOYS

I. INTRODUCTION

The desirability of obtaining direct measurements of currents in the open ocean, particularly in deep water, is recognized by all oceanographers. Most of the problems with which oceanography deals involves, indirectly or directly, the deep ocean circulation on some scale. However, the difficulties of making significant measurements of deep currents is all too apparent to those who have thought about them, and more particularly to those who have tried them. No really satisfactory method of measurement exists.

A review paper by Böhnecke (1955) describes a variety of current meters and provides a useful reference to techniques up to that date. More recently, a number of workers have improved the Lagrangian (trajectory tracing) techniques. Most importantly, the work of Swallow (1955, 1957) with his neutrally buoyant floats has provided a method which is generally applicable to measurement of the slower deep-water currents. Despite the difficulty of extending this technique to long time series over large areas, it has provided a completely new insight into the movement of the deep water, and a redefinition of the desired type of Eulerian measurement. In particular, Swallow's measurements often show variability (turbulence) in the measured currents, the velocity of which is large compared to the residual slow drift. Where such variability is encountered, the significance of short term measurements is, of course, in serious doubt. While measurements of a few hours or a few days are probably significant in the case of strong, well-defined currents (on the axis of the Gulf Stream, for instance), the situation in the deep water is considerably more complicated. The problem being studied in the latter case is the partition of energy in the turbulent field among the various scales of motion.

The tracking of neutrally buoyant floats, drogues or dye patches can be used to obtain sufficient data for this problem if the measurements can be continued for long-enough periods of time. Many possibilities exist for improving these techniques so that longer experiments can be carried out. However, as the time of the measurement increases, the possibility of equipment which may be left at sea, without the necessity of keeping a ship out with it, becomes increasingly attractive.

It is the purpose of this paper to describe an anchored buoy station and the associated instrumentation, which is capable of providing long time series of current measurements simultaneously at several depths in the open ocean. The authors make no claim that this technique is an easy one, or is a cure-all to the deep current problem. However, as will be seen below, about 75 such stations have been set for various periods during the last year. Not all the stations lasted, but a significant percentage did, and the causes of failure have been analyzed in several cases. Not all the current meters have functioned properly, and only a relatively few really good records have been obtained so far. However, the difficulties appear to be remediable, and the work is proceeding.

In developing a moored station for current measurements, two separate problems must be faced. First, a buoy and mooring system must be produced which may be expected to last (with an acceptable rate of attrition) under all sea conditions. Secondly, a current meter capable of operating under the conditions in the mooring must be provided. Details of the design and the reasons for them are given below, but one generalization should first be mentioned. At the start of this work, a basic decision was made that the mooring would have no electrical conductors. While a conducting-cable mooring is undoubtedly feasible, it did not seem wise to predicate a large effort at sea on the success of such a mooring at the start of this project.

Over the last few years, several attempts at deep sea moorings by various groups have indicated that reasonably sized stations, if properly constructed, can be expected to last for extended periods of time. Some of these have been taut-wire moorings utilizing subsurface floats; others have been rope or wire slack-line moorings. By whichever technique, it appeared that a moored buoy system for current meters could be built at a reasonable cost, and to this end the authors set a rope mooring, similar to those described below, in 1500 fathoms southeast of Bermuda in mid-December, 1960. This test station was maintained until the end of February, 1961, during which time it was exposed to several periods of the stormy winds which characterize that area during the winter season. Records of mooring tension were made, which indicated that the mooring design was quite conservative for the conditions encountered.

With this background, a line of stations (Figure 1) was undertaken. Figure 2 is a cross-section of this line showing the distribution of instruments in the stations. Because of the large number of instruments involved in the line and potentially large amount of data they would generate, it was determined that each of the internally-recording instruments should record in a format which would permit machine reduction of the data. The spacing of the stations is certainly arbitrary, but it was anticipated that this spacing would be changed, or the line configuration might be changed to other sorts of arrays, as the data indicated this to be desirable, (as has, indeed, been the case).

With this general plan in mind, the required stations and instruments were built during the spring of 1961, and Stations A, C, R and D were set in early May. Stations E, F, G, H, I, J, K, L and M were in place by early June, and an attempt was made to maintain these until June 1962. In addition to these, a number of other stations have been set at various locations. The successes and failures which occurred will be discussed in detail below, following a detailed description of the stations and instruments.

II. THE STATION (Figure 3)

A. The Mooring Cable. The design of a deep anchored ocean station which is to survive the rigors of its environment for long periods of time is not an easy one. The moored buoys with which one is most familiar (navigational markers) are, of course, moored in shallow water, and the technique of making a lasting mooring is one of brute force. While this approach is feasible in shallow water, it is economically impossible in deep water. The exact starting point in the design of an economical deep station is hard to select, but in the case of the station here described, the following design procedure was adopted.

The critical and most costly item appeared to be the cable, and a study was made of available materials, with the object of obtaining the cable with the most favorable strength-to-weight and strength-to-drag ratios. The material selected was polypropylene rope made from .006" monofilament, and the largest size which could be afforded was selected. This rope was 9/16" in diameter and had a guaranteed strength in excess of 5000 pounds; it is easy to handle, and splices, if properly made, are essentially as strong as the parent rope. The density of polypropylene is 0.92 gms/cm^3 and the rope will stretch linearly as it is strained, until it breaks at an extension of about 40% of its original length. This stretching is a very useful property, since the mooring can generate its own scope as required. Since the cable and instruments combine to very nearly neutral buoyancy, the whole length of the cable should stretch uniformly; the instruments should therefore remain at very nearly constant depth under conditions of varying tension. The stretching also serves to absorb the surge of surface wave action.

The rope is supplied in 500 meter lengths ($\pm$ 1%) with thimbles spliced in each end. The use of rope dictated the kind of instrumentation to be used, and the properties of the selected size set many of the design criteria in the rest of the parts of the station.

B. The Surface Float. (Figure 4) The basic consideration in the design of the surface float was that it have sufficient buoyancy so that it could never be towed under by the cable (more correctly by the weak link; see below). Additional desired features were stability, light weight, reasonable size, strength and resistance to damage during launch and recovery operations. To compromise these sometimes mutually exclusive desires, a toroidal shape was selected. The floats were made of 5/16" thick fiberglass (toroidally wound), and filled with 2 pound-per-cubic foot foam. The dimensions selected were 8 feet outside diameter and 3 foot center hole, the weight about 600 pounds, and the ultimate displacement about 6000 pounds. Three equally-spaced stainless steel straps were banded around the float and welded in place; studs for mounting the tower and pads for connecting the mooring bridle were welded to these straps. The straps were then covered over with fiberglass, and the entire float was painted fluorescent orange.

A ten-foot high tripod tower, made from 3-inch aluminum channel, was mounted on the float, and a platform provided for a light and a wind speed and direction recorder. In addition, a small transistorized radio transmitter (2 watts at 2398 kc) and its antenna and keyer were installed. The keyer sends the buoy call sign and a long dash for direction-finding purposes every 20 minutes. The transmitter can generally be heard recognizably for about 200 miles, and has sufficient strength for direction finding at a range of about 100 miles. It is used only for location purposes, not for data telemetering. Later experience showed that the floats had a tendency to capsize in winds of force 10 or greater, so an apex float of fiberglass-covered foam was added. A radar reflector is enclosed in the foam of this float but it is of doubtful value, being good target in calm weather when it is least needed, and a poor target in rough weather when it is badly needed.

C. The Ground Tackle. (Figure 5) The anchor and its associated parts is one of the most difficult parts of the mooring system to design. Since the instruments used in the mooring are internally recording, the mooring must be recovered to retrieve them and their records. The question as to whether the anchor should be retrieved or left behind is an open one; in the present design it is usually retrieved when the mooring is pulled. To protect the system against loss if the anchor is badly fouled, a weak link is inserted between the cable and the ground tackle. This link has a strength of about 4000 pounds, and is made from a short length of polypropylene rope, of construction similar to the main cable, but having a diameter of 15/32 inch. A hydraulic weak link, held together by the ambient hydrostatic pressure acting on a piston, has also been successfully employed where the anchor is to be expended.

A twenty-foot length of one-inch diameter polypropylene rope has been inserted between the weak link and the anchor chain. This was included to provide some flotation for the end of the anchor chain, and to provide sufficient strength to withstand chafing if minor fouling occurred.

In a short-scope mooring, the vertical component of the tension is much greater than the horizontal. Time-honored anchoring systems have been designed for the long-scope, shallow water case, in which the vertical component is readily rendered negligible. The Danforth anchor, until recently employed, requires a lead 8° or less from the horizontal. A dead weight, heavy enough to counteract most or all of the anticipated vertical component, is therefore placed just above the anchor. Substitutes for dead weight, such as anchors explosively driven into the bottom, have been considered, but such devices have not yet shown adequate reliability.

The anchor should, of course, hold in a mud bottom. In the Bermuda test station, the ground tackle consisted of 500 pounds of 1/2 inch chain, and a 65-pound Danforth anchor. It appears that the mooring dragged a few miles off station; indeed, it is inferred from the measured mooring

tension that its vertical component was at times greater than the weight of the ground tackle. Greater dead weight was therefore indicated, and it was soon realized that lumped constants are in this case equivalent to distributed constants. Cast iron is much cheaper than chain, and easier to handle on deck. Thereafter, 800-pound cast iron clumps were substituted for most of the chain, two per mooring in the Gulf Stream, and one per mooring elsewhere. The Danforth anchor was increased to 90 pounds. Actual mooring tensions, which have been inferred from the appearance of the surface float or actually measured, have generally been a few hundred pounds, rising to perhaps 3000 pounds in Gulf Stream moorings. The fact that the stations do not drag, and that the ground tackle can be recovered without parting the weak link, indicates that a reasonable compromise has been achieved.

At the time of this writing, a new anchor design (Stimson, 1963) is being evaluated. It consists of a faired iron casting, so shaped and suspended as to bury itself in the bottom and supply the horizontal holding power. This design is cheaper, easier to handle on deck, and less susceptible to fouling during the launching procedure than the present design. It has been tested in three sizes: 800 and 1500 pounds, which will be recovered, and an expendable version of about 3000 pounds for Gulf Stream moorings.

D. Launching the stations. As mentioned above, the mooring cable is provided in 500-meter lengths, and the instruments are designed to act as tensile links between the lengths of rope. Prior to launching, the uppermost instrument is connected to the chain leader below the float bridle, and the first length of rope is shackled to lower end of the instrument. At the station location, the water depth is measured, and the number of 500-meter lengths of rope selected. If the water depth is such that 500-meter lengths do not make up conveniently to the depth, a 250-meter length is available to be used as the bottom piece. The surface float is then set over the side, and the first instrument is eased into the water. The ship is then gotten under way at about 2-3 knots, and the rope pays out from its reel. When only the last 50 meters of the rope are left on the reel, the ship's engines are stopped and as the vessel slows, the line is stoppered off. The second instrument is then shackled in and eased over, the stopper released, and the procedure repeated until the last length is out. The chains to the ground tackle are then shackled in and the weights, chain and anchor cast off. A 5000-meter station can be set in this way, from any vessel large enough to venture offshore, in somewhat less than one hour. After the anchor is let go, the ship is maneuvered in a wide arc back to the surface float, which is seen to be towing through the water at about 2-3 knots. This movement ceases abruptly when the anchor bottoms, which in the case of a 5000-meter station requires about 1/2 hour. The ship is normally maintained near the float until successive fixes indicate it is moored.

E. Retrieving the Stations. On recovery, the surface float is approached and griped to the side of the vessel, so that a hook can be snapped into a ring at the apex of the tower. The float is then hoisted well into the air,

and a chain hook is used to stopper off the leader below the bridle. The float is then lowered to the deck and disconnected below the bridle. A pendant is then run out through a large block (fisherman's hanging block) which will pass shackles and thimbles as required. The mooring may be pulled on a capstan, but great care must be exercised in pulling the slippery rope with a large load in this way. This procedure is, in fact, so dangerous that it should be discouraged. On the R/V CHAIN, a large drum puller is used. This is a hydraulically powered drum (50 HP), 4 feet in diameter and 8 feet long, equipped with a level wind. After an instrument has been removed, a pendant is run out from one end of the drum through the hanging block, and snaphooked to the top of the length of rope to be pulled. The drum is then started and the entire 500 meters is spooled in one layer on the drum. The next instrument to be removed is then hanging below the block. The rope below this instrument is stoppered off and the instrument removed. Meanwhile, a pendant is run out from a slack spooling machine having 12 drums made from the original rope reels. Each reel is hydraulically powered by its own motor, and provides a pull of about 20 pounds on the rope as it is spooled off the big drum. Shortly after this respooling from the big drum to the storage reel is started, the pulling drum is stopped, and a pendant run out from the end opposite to that used on the last length. This is hooked to the end of the next length of rope to be pulled. The drum is then run (in the opposite direction from that used in pulling the previous length), the second length laying on to the big drum, and the first length spooling off into the storage reel. This procedure is continued until the ground tackle surfaces and is stoppered off. The station is then relaunched as described above, the line spooling off the 12-drum winder, which free wheels when the motors are off. The ground tackle is not normally brought aboard.

During the retrieving operation, the vessel must be steamed in a careful and positive manner, to keep the mooring lead vertical. Figures 6 and 7 show the pulling drum and the spooling machine.

F. Notes on Fittings and Mechanical Parts. Polypropylene rope is considerably stronger than manila rope, and will crush rope thimbles designed for the latter material. A type of thimble designated for "heavy wire rope" should be used with polypropylene. Splices around these thimbles should be made by taking four full tucks and two split tucks, taking out about one-third of the yarns on each split tuck. When the tails of these tucks are cut off, about 2 inches should be left hanging out. This makes a ragged-looking splice, but the stretch of the rope as it is strained requires that these pigtails be left on.

One-half inch galvanized shackles, of the variety referred to as "round pin anchor shackle", are used in the moorings. The pins in these shackles are loose-fitting and held by cotter pins, and are much easier to remove than screw pins when corroded or under strain. At the connection below the instrument, or at points where two lengths of rope are joined without an instrument, a pear-shaped sling ring 4 inches in diameter is used. This provides a point where the mooring under tension can be stoppered without jamming the shackle, which must be removed to get the instrument aboard.

Since the instruments are used as tensile links between the lengths of rope in the mooring, care must be taken to provide strength in excess of 5000 pounds across them. If they are held together with screws or tie rods, care must be taken not to overstress these during assembly. Also, mechanical parts subject to stress corrosion must be avoided. Corrosion of this type has caused the loss of some stations.

It is sometimes convenient to make attachment points on instruments by means of bails or U-bolts secured by nuts. (See the current meter, below.) If these are used, the threads should be upset behind the nut, or the nuts should be welded on. Several stations were adrift before it was discovered that lock washers are not sufficient.

G. Instruments. The instruments as they were originally developed for use in the buoy line differ in some details, but not in operating principle, from those currently being constructed to continue this work. In the description that follows the present form of the instruments will be described. All of the instruments are internally recording, there being no electrical connection to the surface float or any other central recording point. Various recording media were investigated for this purpose and it was decided to use a digital format on photographic film in all of the instruments. This provides a record which with proper equipment can be read directly into a computing machine for detailed analysis of the data. However, it is also possible to reduce the records to analog form (for instance, in the case of the current meter, analog records of speed and direction vs time) independent of a general purpose digital computer.

III. THE CURRENT METER

A. Specifications. The instrument is designed to record internally the direction and speed of currents; it may be lowered or used as a link in the mooring system. The instrument is cylindrically symmetrical and does not require orientation into the current. The recording consists of 100 feet of photographic film on which the speed is recorded in two channels and the direction in 14 channels running parallel to the length of the film. Two additional channels are occupied, one by clock pulses and one by a continuous line. These additional channels are required in the readout of the records.

Readout can be accomplished by projection of the records and reading by eye but the basic consideration in design was to provide an instrument to store a large number of current vectors for machine readout and computation. Each 100 foot film stores approximately 250,000 directional readings and records the speed associated with these directions over some selected time interval. The limitation of storage is not inherent in the film and modifications to increase this by a factor of five, without increasing the amount of film, would be fairly easy to incorporate.

Provision is made so that the recording can be made continuously at 1/8 inch per minute (6 1/2 days of record) or with clock control so that one minute recordings (1/8 inch of film) can be made three times per hour. The mode of operation must be selected before the instrument is closed in its pressure case. Alternate rates of film advance or numbers of readings per hour are readily accomplished by change gears or by changing the number of switch lobes on the clock.

The general design criteria for the instrument are as follows:

Speed measurement from the Savonius rotor:
    a. minimum starting speed: 0.01 knot (0.5 cm/sec)
    b. maximum speed: 5 knots (250 cm/sec)
    c. approximate rotation rate: 100 RPM per knot, linear above 0.04 knot (see calibration curve below)
    d. time constant (response to step function of current): 10 seconds
    e. tilt error: 3% at 5°, 6% at 10°, 12% at 20°, 20% at 30° (all tilt errors cause the instrument to read low)
    f. accuracy: at 0.01 knot $\pm$ 100%, at 0.3 knot $\pm$ 3%, at 3 knots $\pm$ 3%.
    g. recording: one pulse for every revolution and one pulse for every 10th revolution of the rotor.

Relative bearing of current to instrument case as given by the vane:
    a. within 10° at 0.01 knot.
    b. within 2° (1 binary bit) at 0.03 knot
    c. balanced in sea water to be insensitive to tilt
    d. recording: 7 level Gray binary number in 7 channels (resolution 2.5^o)

Compass bearing, giving the orientation of instrument case in the Earth's magnetic field:
    a. sensitivity: better than 1°
    b. maximum tilt angle before binding: 45°
    c. recording: 7 level Gray binary number in 7 channels (resolution 2.5^o)

Recording system:
    a. total number of 1 minute recordings: 9600
    b. film advance by chronometrically controlled 6VDC motor: 0.1% timing accuracy
    c. timing by solenoid wound clock: 0.01% timing accuracy (applicable to intermittent mode)
    d. length of cycle when clock controlled: 1% (applicable to intermittent mode)

Mechanical design:
    a. maximum recommended depth for pressure case: 6000 meters with safety factor of 1.5 (9000 meters calculated collapse depth).
    b. maximum deflection of center of end caps at calculated collapse pressure (9000M): 0.015 inches
    c. maximum allowable tensile load across instrument (bail to bail): 7000 pounds.
    d. external parts: 7075-T6 aluminum (hard anodized and epoxy painted), 18-8 stainless steel fastenings (welded where approp.

B. General Layout and Operation. Figure 8 shows the layout of the instrument in its normal vertical position. The vane cage at the top and the rotor cage at the bottom carry bails to which attachment is made. The vane carries a magnet near its base and this couples through the upper end cap to the vane follower. A magnetic assembly on the vane follower tracks the vane and carries with it an encoding disc. The output of the follower is seven fiber optics light pipes which lead to the field of view of the camera and appear as 7 light spots (channels) either lit or not lit depending on the vane orientation. The compass is very similar to the vane follower except that the magnet assembly is gimbaled; the output is identical to the vane follower providing seven channels which encode the orientation of the instrument case in the Earth's magnetic field. Again the connection from the compass to the field of view of the camera is fiber optics light pipes. As can be seen in Figure 9, the camera is located between the vane follower and the compass. The clock and several of the electrical components are mounted on the field of view platform together with the block into which the light pipes plug. Below the compass is located the 6 volt battery which powers the instrument and is sufficient for the 100 foot data strip. The rotor is mounted in the lower cage and, like the vane, is coupled through its end cap magnetically. In this case the follower is recessed into the end cap and is simply a light chopper which provides a light pulse for each rotation of the rotor and one for every 10th rotation. These pulses are transmitted to the field of view of the camera by fiber optics where they occupy two channels. The appearance of the record is shown in Figure 9. The various components will now be discussed in more detail.

C. The Rotor and Rotor Follower (See Figure 10). The Savonius rotor used here consists of two sections each having two semicircular blades. In each section the blades are mounted 180° apart and opposed. The top section is oriented 90° to the lower one giving a four-lobed torque distribution. More sections might be added at other angles but the above arrangement appears to be sufficient for speeds down to 0.01 knot. The rotor is constructed by gluing together pieces moulded from polystyrene. With its pivots and magnets attached it weighs about 32 gms. in sea water. The pivots of the bearing assembly are mounted on the rotor. These consist of tungsten carbide rods .093 inch in diameter and 1/2 long which are moulded into phenolic holders which in turn are screwed to the rotor. The pivots project 1/8 inch from the holders and are polished to a mirror finish on the hemispherical ends and for a length of .100 inch from this end.

The bearings in which these pivots ride are mounted one on the end cap and one on the end plate between the bail nuts. The bearings consist of a stainless steel socket head screw (1/4-28, 1/2 inch long) with a broached hole in one end. This hole is .100 inch in diameter and is given a high polish in the broaching operation. A highly polished tungsten carbide end stone is set in the bottom of the hole, the bearing depth being .090 inch. The bearing in the end cap is locked with a stainless steel nut and is not adjustable. The bearing in the end plate is locked by a set

screw from the outside after proper adjustment of end throw. The radial
slope of the bearing pivot combination is about .007 inch and normally about
.009 inch (one quarter turn of the bearing from binding contact) of end
throw is provided. This gives a very light containment of the rotor in the
bearings. Figure 11 shows the rotor calibration curve.

The rotor follower consists of a magnet assembly and pinion mounted
on a tungsten carbide shaft which turns on jewel bearings and revolves with
each rotation of the rotor. The pinion provides 10:1 reduction to a spur
gear mounted on a second jewel bearing mounted shaft carrying a cup which
surrounds a small light bulb. At one point on the cup is a small hole
from which a pulse of light is emitted for each rotation of the cup (10
rotations of the rotor) and at another level on the cup there are 10 holes
which provide a pulse for each rotation of the rotor (see Figure 12). Two
light pipes plug into the side of the follower to transmit these pulses
to two channels in the camera's field of view. Figure 13 shows the
design of the light pipes which, except for length, are identical to the
other light pipes used in the instrument.

D. The Vane and Vane Follower (See Figure 14). The vane consists
of a 3/4 inch diameter delrin (acetal plastic) rod which is fitted with
a 1/8 inch thick polyethylene fin. The rod is tapped to accommodate pivots
identical with those used on the rotor and described above. It is also
drilled to take a Teflon-covered magnet which is set with its north-seeking
pole forward on the vane. A small counter balance weight is required at
the lower back of the fin to provide balance in sea water. The bearings
for the vane are mounted and adjusted identically to those for the rotor.
The weight of the vane in sea water is about 37 gms.

The vane follower (see Figure 15) consists of a liquid-filled chamber
in which is a jewel bearing mounted shaft carrying a magnet assembly which
causes the shaft to follow the vane. A seven level Gray binary optical
encoding disc is mounted on this shaft. The disc is shown in Figure 16 and
is made by silk screen printing on 1/16 inch thick plexiglas. Mounted
from one side of the chamber is a light source consisting of a small
bulb inserted in a hole in a plexiglas rod. The rod is painted white
to provide diffuse reflection and over that black to prevent spurious
reflections. A clear line is scraped on one side of the rod which
provides illumination below a radial line of the disc. Seven light pipes
are mounted above and along this line spaced so that they are centered
in the seven encoding levels. The light pipes are spaced about .020 inch
from the top of the encoding disc which, in turn, is about .010 inch from
the bottom of the chamber. As the vane (and therefore the follower) is
turned, various combinations of the pipes will be illuminated as a function
of azimuth. The chamber is filled with compass-grade kerosene and sealed
by o-rings; a small bellows is provided to take care of thermal expansion
and contraction of the fluid.

E. The Compass (See Figure 17). The compass is identical in opera-
tion to the vane follower; it differs only in physical shape and in the
form of the magnetic assembly. This assembly consists of a jewel bearing
mounted ring (which carries the encoding disc) in which an internal post
is mounted. The compass card rides on a standard compass jewel on this
post and couples to the ring by means of a wire whisker which fits in a
slot in the ring. Thus the ring is driven by the compass card but the
card is free to tilt in any direction to an angle of $45°$. The compass is
liquid filled and equipped with an expansion bellows. The spacing of the
light, encoding card and light pipes is identical with that in the vane
follower above. Both the compass card and the entire ring assembly are,
of course, balanced. An additional light pipe plugs into the light source
in the compass to provide a continuous trace in one channel of the record.

F. The Camera and its Field-of-View (See Figure 18). The camera is
a simple one in which the image of the field-of-view is registered on the
film directly on the blackened sprocket. The sprocket is driven through
a worm reduction by a chronometrically controlled 6VDC motor giving a film
speed of 1/8 inch per minute. As the sprocket is driven, film is pulled
from the supply reel and taken up on the take-up reel through a slipping
o-ring drive.. The motor drive also includes a cam and microswitch which
controls the intermittent motion when the instrument is clock controlled.
(See section G for electrical details).

The focus of the camera as at the underside of the plexiglas field of
view platform where the tips of the 18 light pipes pass through a moulded
block to give proper spacing and butt up against the plexiglas (to provide
protection from dirt and damage). This platform is blackened (except
where the line of light pipes shows through) to prevent the camera from
seeing the illuminated compass below.

G. The Electrical Circuit and Operation. Figure 19 is the circuit
diagram for the instrument. The single 6 volt battery is specially made
for the instrument and consists of 36 F size cells in series-parallel.
The operation is as follows: With the instrument inverted the Mercury
switch (S_1) turns it off; it may be loaded and made ready for use ashore
and stored in this position. With the instrument right side up and
switch S_2 in the down position (on the diagram) the camera motor runs
and the three lights L_v, L_r, and L_c are lit for the vane, rotor and com-
pass respectively. The recording is then made continuously and will last
for about 6 1/2 days (continuous operation mode).

The alternative mode of operation (clock controlled) is obtained
with S_2 in the up position (on the diagram). The clock will be running
but no other action will occur until the clock switch (S_3) changes poles.
At this time the camera motor will run through its microswitch (S_4) until
the cam trips S_4 and it stops. The motor will run about 50 seconds during
this phase and this will be the data recording period. At the start of
this action (when S_3 makes) a pulse occurs through the blocking capacitor
(C) and the read pulse (timing pulse) light L_t flashed in its channel. No
further action will occur until about 10 minutes later when S_3 trips back
to its original position and the motor runs a short time (about 10 seconds)
to return S_4 to its original position.

IV. OTHER INSTRUMENTS

While the current meters are the primary instruments for which the moorings are used, there are several useful auxiliary instruments which will now be described (in less detail).

A. The Wind Recorder. The wind recorder can be seen in Figure 4 and is identical with the current meter in its recording system.

In this instrument the direction is again obtained from a vane but the shaft of the vane passes directly through the lid of the instrument via waterproof ball bearings and the binary encoding disc is fastened on the end of the shaft. Thus no follower is required. The wind speed is obtained from anemometer cups equipped with contacts that make every 1/60th mile and every 1/6th mile of wind. Two light bulbs are lit through these contacts and the light is piped to the field of view of the camera exactly as from the rotor follower in the current meter described above. The compass is identical with that used in the current meter and thus the records from the two instruments are identical except for the speed calibration.

B. The Inclinometer. The measurement of tilt angle and direction in the mooring line is of interest in describing the performance of the mooring and also since the current meter speed calibrations are somewhat sensitive to tilt. An early form of this instrument used a group of six pendulums which made electrical contact at 2°, 5°, 10°, 15°, 20°, and 30°. These contacts lit light bulbs which simply marked 6 channels on the film off or on. Direction of tilt was obtained from a binary encoding disc similar to the vane follower in the current meter except that the magnets were replaced with an off-set weight which swung the follower to the low tilt side. The same compass is used as in the current meter. The readout of the above inclinometer is obviously not identical to that of the current meter. In a newer form of the inclinometer the amplitude of tilt is recorded as a discrete number of pulses in the film channel corresponding to the rotor channel in the current meter. This permits the record to be reduced by the same scanning system as in the case of the current meter.

C. The Tension Recorder. The tension in a mooring line is of considerable interest in describing the performance of the mooring and assessing its probable life. It is possible to estimate the mooring tension quite easily by the extent to which the surface float is pulled down into the water as observed from a nearby vessel. However, it is desirable to have longer tension records particularly under adverse conditions such as storms and strong and variable surface currents. To provide such records a tension recorder in which the mooring tension is converted to hydraulic pressure which is then recorded was designed. Figure 20 shows the transducer mounted on a pressure case end cap. The whole instrument is used as a tensile member in the mooring and obviously this must be near the top of the mooring since the piston is forced in by ambient hydrostatic pressure in opposition to the pressure generated by tension. This pressure is recorded on film by replacing the pointer of a pressure gauge with a binary disc and picking off with light pipes or alternatively a pressure potentiometer is used with a small strip chart recorder.

D. __Temperature Recorders.__ A variety of temperature recorders are available which could be adapted to use in the moorings. Unfortunately none of the commercially available instruments have sufficiently accurate provision for depth recording in association with the temperature measurement. The depth recording is necessary because one is presumably interested in the temporal changes of temperature at a fixed depth but, since there is a natural vertical gradient in the ocean, it is necessary to be able to sort out temperature changes due to vertical movement of the instrument. For instance, if the natural gradient in the deep water is about $1^{\circ}C$ per 1000 meters and one is interested in the temperature to $.01^{\circ}C$ it is necessary to know the depth of the instrument to better than 10 meters (preferably about 1 meter) to tell changes due to vertical motion from changes with time at a fixed level. Instruments with this capability are under test at present and will be added to the buoy work when satisfactory performance has been demonstrated.

E. __Miscellaneous.__ In addition to the above instruments designed for physical measurements it is worth noting that a variety of other experiments which require relating long observation time are possible from the moorings. In particular, a number of exposure panels for metallurgical corrosion studies in the deep ocean have been installed in the moorings at various times and panels for the study of fouling by marine organisms in the deep water have been exposed. Such experiments are easily added to the moorings and are to be encouraged. In general instrument packages weighing a few hundred pounds and having volumes of a few cubic feet do not present any serious problem to the mooring.

V. STATIONS SET MAY 1961 TO DECEMBER 1962

Table 1 is a listing of the buoy stations which were set between May 1961 and December 1962. The stations are numbered chronologically, with the test station set in December 1960 included as number one. It is difficult to summarize in a short table all the details available on the fate of the stations; however certain pertinent facts with regard to stations which were lost or only partially recovered are given. The surface floats are often sighted by ships or aircraft and reported through various channels to the U. S. Navy Oceanographic Office for inclusion in NOTICE TO MARINERS. In cases where a station was lost there may be an indication in Table 1 of "days on station" marked with an asterisk. This means a sighting in position was reported so the station lasted at least that many days. If no asterisk follows the number of days on station, recovery was made at the planned time. Under the heading of "notes on recovery" is indicated whether a complete recovery of all instruments was made or only a partial recovery was achieved. The recovery is listed as partial if any current meters were lost. In some cases this means that most of the instruments were recovered. Partial recoveries tend to fall into two classes: those where the station was adrift and those where the buoy was found in station but mechanical difficulty or cordage damage prevented full recovery. These are designated "adrift, partial" and "on station, partial" respectively.

TABLE 1

STA. NO.	DATE SET	LAT.	LONG.	DEPTH (Meters)	DATE RECOVERED	DAYS ON STATION	NOTES ON RECOVERY
1	11 XII 60	32-14	64-33	3000	28 II 61	79	complete
2	23 II 61	22-58	52-41	5000	23 III 61	30	complete
3	9 V 61	A	A	60	22 V 61	10*	adrift, partial
4	9 V 61	C	C	160	28 V 61	17	complete
5	9 V 61	D	D	2600	3 VI 61	25	complete
6	10 V 61	R	R	160			lost
7	24 V 61	44-55	48-10	90		30*	lost**
8	24 V 61	44-53	48-54	1000	15 VII 61	52	complete**
9	25 V 61	44-51	48-38	2000	15 VII 61	51	complete**
10	29 V 61	A	A	60	21 VII 61	53	complete
11	30 V 61	E	E	3400	22 VII 61	53	complete
12	30 V 61	F	F	3600	23 VII 61	53	on station, partial
13	30 V 61	G	G	5000	?		adrift, float only
14	30 V 61	H	H	5000	6 VI 61		adrift, float only
15	31 V 61	I	I	5000		56*	lost
16	31 V 61	J	J	5000		3	lost
17	1 VI 61	K	K	5000	26 VII 61	56	complete
18	1 VI 61	L	L	5500		4*	adrift, partial
19	1 VI 61	M	M	4500	28 VIII 61	58	complete
20	3 VI 61	D	D	2600	22 VII 61	49	complete
21	3 VI 61	C	C	160	21 VII 61	48	complete
22	20 VI 61	B	B	100	21 VII 61	32	complete
23	20 VII 61	40-15	72-00	60	15 VIII 61	25	complete
24	21 VII 61	A	A	60		11*	lost, hurricane
25	21 VII 61	B	B	100		56*	lost, hurricane
26	21 VII 61	C	C	160		47*	lost, hurricane
27	22 VII 61	D	D	2600	28 X 61	97	complete
28	22 VII 61	E	E	3400	14 IX 61	53*	adrift, partial
29	23 VII 61	F	F	3600	18 X 61	87	complete
30	23 VII 61	G	G	5000	30 VII 61	?	complete, adrift
31	24 VII 61	H	H	5000	? IX 61	14	adrift, partial
32	26 VII 61	K	K	5000	?	5*	complete, adrift
33	28 VIII 61	M	M	4500	4 XII 61	129	adrift, partial
34	28 VIII 61	L	L	5500	3 XII 61	128	adrift, float only
35	29 VII 61	J	J	5000		32*	on station, partial
36	31 VII 61	38-38	69-04	3500	19 X 61	80	complete
37	7 X 61	J	J	5000			lost
38	7 X 61	30-00	79-15	800	10 XI 61	34	complete**

TABLE 1 (Cont.)

STA. NO.	DATE SET	LAT.	LONG.	DEPTH (Meters)	DATE RECOVERED	DAYS ON STATION	NOTES ON RECOVERY
39	28 X 61	D	D	2600	18 VI 62	233	complete
40	28 II 62	58-40	40-35	5500			lost
41	31 III 62	51-25	49-28	5500	2 IV 62	3	complete
42	14 III 62	C	C	160		10*	lost
43	14 III 62	E	E	3400	19 III 62	5	complete
44	15 III 62	F	F	3600	20 III 62	5	complete
45	15 III 62	G	G	5000	18 III 62	2*	adrift, partial
46	16 III 62	H	H	5000	21 III 62	5	complete
47	16 III 62	I	I	5000	23 III 62	7	on station, partial
48	19 III 62	E	E	3400	18 VI 62	90	on station, partial
49	20 III 62	F	F	3600		75*	lost
50	21 III 62	H	H	5000			lost
51	23 III 62	I	I	5000			lost
52	24 III 62	D	D	2600			lost
53	31 III 62	45-28	48-51	90		71*	lost**
54	31 III 62	45-24	48-34	600	30 V 62	61	complete**
55	31 III 62	45-19	48-01	1700	30 V 62	61	complete**
56	5 V 62	Pacific	Ocean		13 V 62	8	adrift, partial
57	5 V 62	Pacific	Ocean		17 V 62	12	complete
58	5 V 62	Pacific	Ocean		18 V 62	13	complete
59	5 V 62	Pacific	Ocean		18 V 62	13	complete
60	5 V 62	Pacific	Ocean			1*	lost
61	11 VI 62	34-28	66-15	5000	15 VI 62	4	adrift, float only
62	11 VI 62	34-04	66-03	5000	15 VI 62	63*	on station, partial
63	11 VI 62	K	K	5000			lost
64	11 VI 62	34-33	66-06	5000	14 VI 62		adrift, partial
65	12 VI 62	34-16	66-03	5000	27 IX 62	107	complete
66	12 VI 62	34-03	65-54	5000	3 X 62	113	on station, partial
67	12 VI 62	L	L	5500		70*	lost
68	12 VI 62	33-53	66-00	5000		48*	lost
69	13 VI 62	33-55	66-13	5000	3 X 62	112	complete
70	13 VI 62	33-56	66-38	5000	2 X 62	111	on station, partial
71	13 VI 62	33-55	67-21	5000		85	lost
72	14 VI 62	M	M	4500	2 X 62	110	on station, partial
73	27 IX 62	34-33	66-14	5000	4 X 62	7	complete
74	27 IX 62	34-30	66-09	5000	4 X 62	7	complete
75	1 X 62	34-37	74-31	4000		2*	lost
76	3 XII 62	28-39	75-59	5000	13 XII 62	10	complete
77	3 XII 62	28-42	75-49	5000	13 XII 62	10	complete
78	8 XII 62	28-33	75-47	5000	13 XII 62	5	complete

** indicates stations set by persons other than the authors

As can be seen from the table, a number of stations have been set at locations other than those shown in Figure 1. In addition, some of the stations in that line were discontinued in June 1962 in favor of a triangular array centered on 34-30 N and 67-00 W and having a variety of spacings between buoys. These were stations 60-to 73 and the partial recoveries in these stations were entirely due to damaged cordage, apparently caused by fish bites. Presumably the lost stations 62, 66, 67 and 70 were victims of the same difficulty since all stations in this area showed considerable cordage damage.

Other generalizations can also be made. Stations G, H, I and J of Figure 1 are swept by strong currents of the Gulf Stream. Sightings of stations at these locations often showed currents of three to four knots flowing past the surface floats. With the exception of number 15 no stations lasted at these locations for more than a few days and few recoveries were made. Examination of parts of recovered stations indicated that failures were due to stress corrosion, fatigue and wear on metal parts, but correction of these problems as they came to light did not improve performance in these locations. More recently considerable evidence has accumulated which indicates that under high stress (more than half of rated break strength) the polypropylene rope will creep, continuously increasing its length and decreasing its diameter until failure occurs. Preliminary experiments indicate that nylon is less subject to this non-elastic behavior and is to be preferred to moorings subject to strong currents.

In the fall of 1961 two hurricanes passed along the line of stations. Hurricane Esther crossed the northern half of the line three different times and hurricane Frances crossed the line just north of Bermuda, then turned and ran directly along the entire line. While most of the surface floats of the stations were damaged by these storms the only stations lost to them were the shallow ones at locations A, B and C.

A rough summary of Table 1 is as follows: Thirteen shallow stations (less than 200 meters water depth) were set. Seven of these were recovered essentially complete. Of the six losses, three were from hurricanes, one was caused by tampering and two are from unknown causes. Fourteen deep stations were set in the Gulf Stream region. Four of these were recovered complete but only after short exposures. Of the ten losses, one was certainly a cordage failure, one was due to winch trouble, two were due to failure of metal parts and in six the cause of failure is not known. Station J is particularly interesting in that no part of any of the three stations set there has ever been recovered. Fifty deep stations (water depth greater than 500 meters) have been set outside the Gulf Stream region. Of these 37 were recovered essentially complete. One was lost due to a tangle during the launch; three were lost to cordage failures apparently attributable to fish bites; one was lost during recovery operation because of winch trouble, and six are lost to unknown causes.

VI. CONCLUSION

The summary above shows that it is possible to set stations of this type in the open ocean and to leave them for periods of two to four months with reasonable chances of success, provided they are not located in a very strong current such as the Gulf Stream. Within the Gulf Stream the only recoveries were on short-term stations when the ship was maintained nearby. Unknown causes still represent a large proportion of the losses but many of the surface floats are eventually recovered and it may be possible to analyze the difficulties which lead to these losses at some future time. More frequent visits by a research vessel would, of course, have reduced the losses, since radio location is possible if the stations have not drifted too far.

A very large number of current measurements has now been accumulated by this technique. Some of these data have been reduced manually and machine reduction of all of them are now in progress. Preliminary analysis indicates that torsional oscillation of the mooring (presumably caused by the laying and unlaying of the twisted rope as tension in the mooring changes) is the most serious problem with which these meters must contend. This rapid rotary motion often blurs the less significant binary channels of the compass and vane and substantially reduces the accuracy of the directional measurement. However, even when the instrument orientation (as shown by the compass) is quite steady the vane often shows disturbingly large fluctuations. Data have been accumulated specifically to test whether these fluctuations are real or whether they are artifacts introduced by the mooring.

Experiments in which a fin is attached to the meter to damp the torsional oscillation indicate that this would be a desirable addition to all the instruments. Also experiments are in progress using a plaited nylon rope which, having a balanced construction, should lead to considerably less torsion with varying strain. It is obvious from the data that current meters closer than 50 meters to the surface are badly contaminated by wave and surface float motion.

All records reduced to date, from whatever depth, show semi-diurnal tides and inertial periods varying appropriately with latitude. In addition there is always shown surprisingly rapid short term variations and there appear to be longer term periodicities. Detailed treatment of the data will be the subject of future publication.

VII. ACKNOWLEDGMENTS

REFERENCES

G. Bohnecke (1955) "The Principles of Measuring Currents", Un. geod.
geophys. int., Assoc. Oceanogr. phys., Publ. Sci. No. 14.

J. C. Swallow (1955) Deep Sea Research 3, 74-81
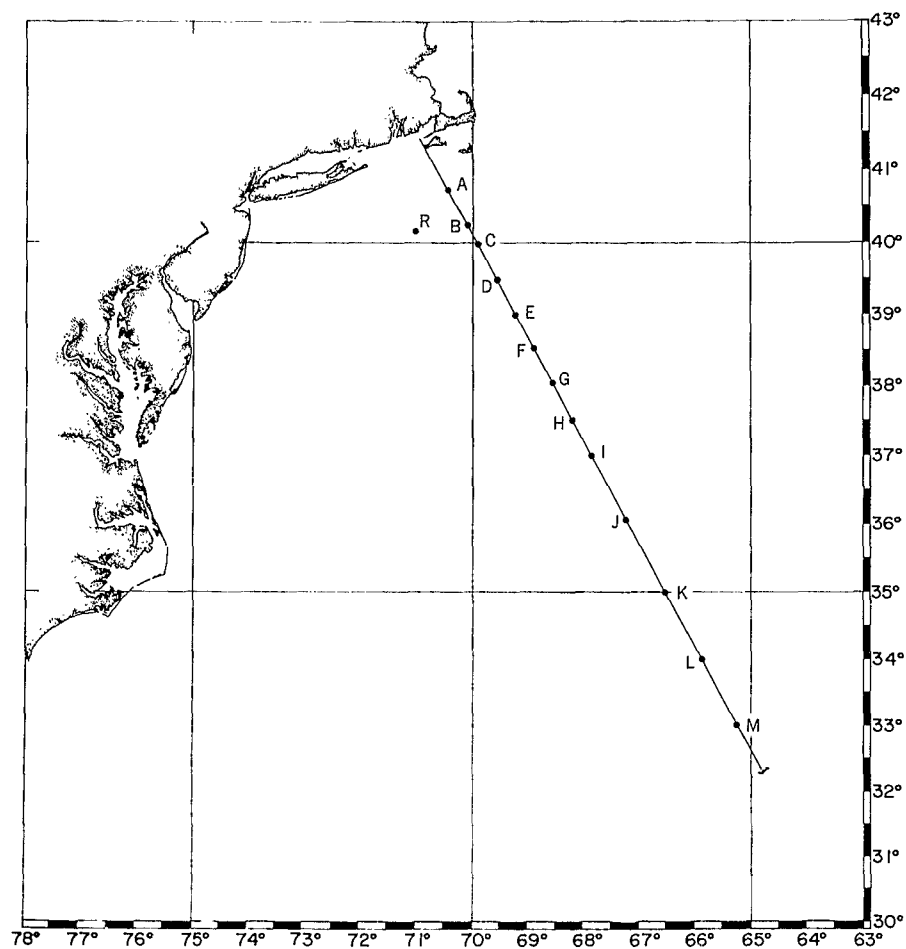
J. C. Swallow (1957) Deep Sea Research 4, 93-104

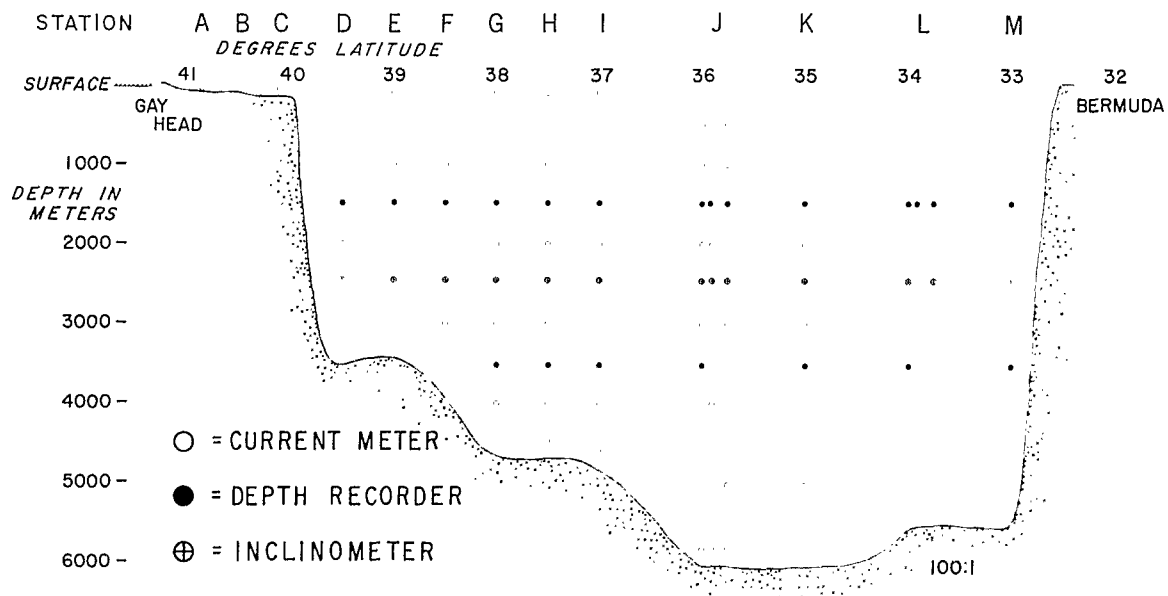FIGURE 1   THE LINE OF STATIONS FROM WOODS HOLE TO BERMUDA

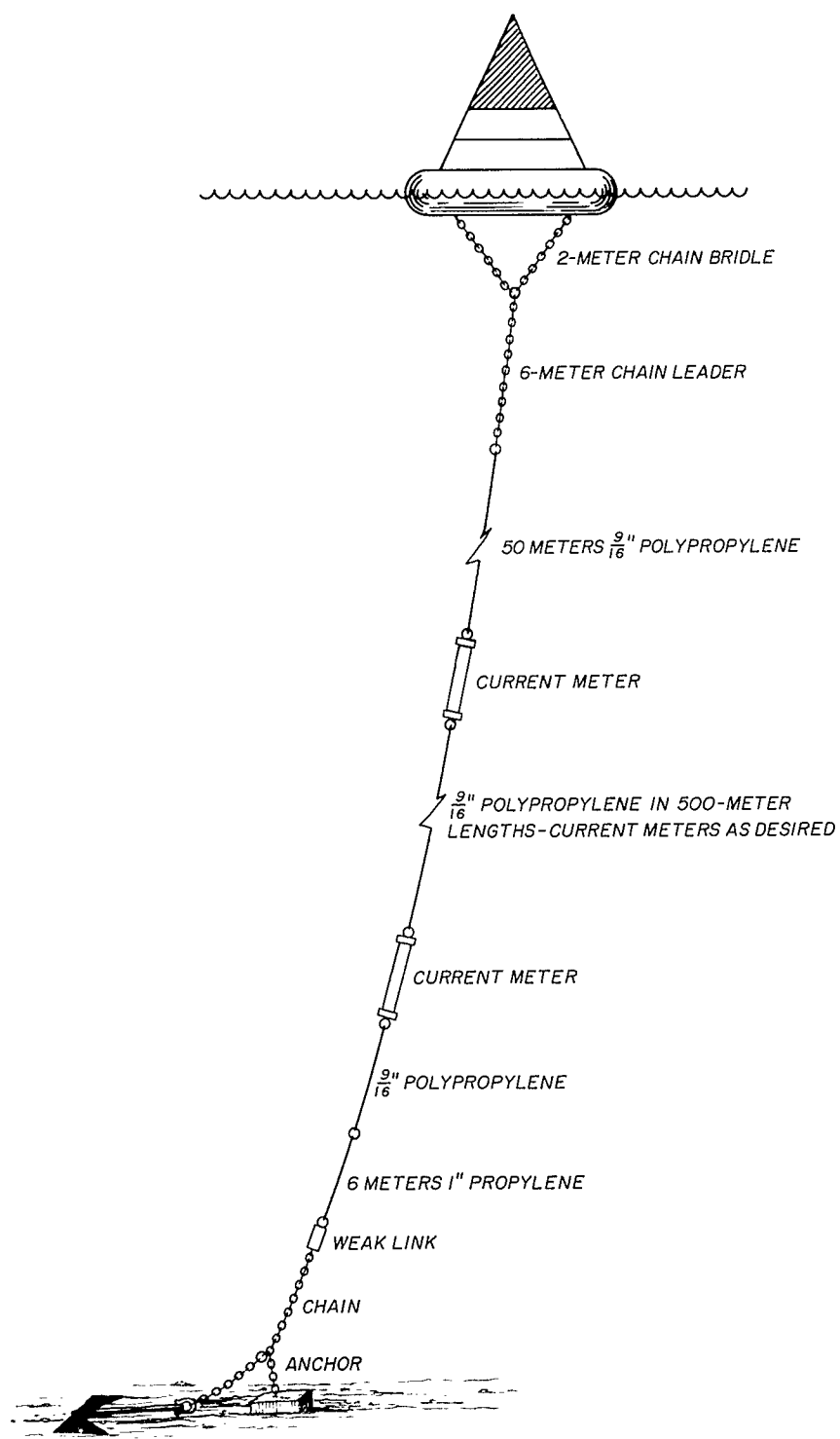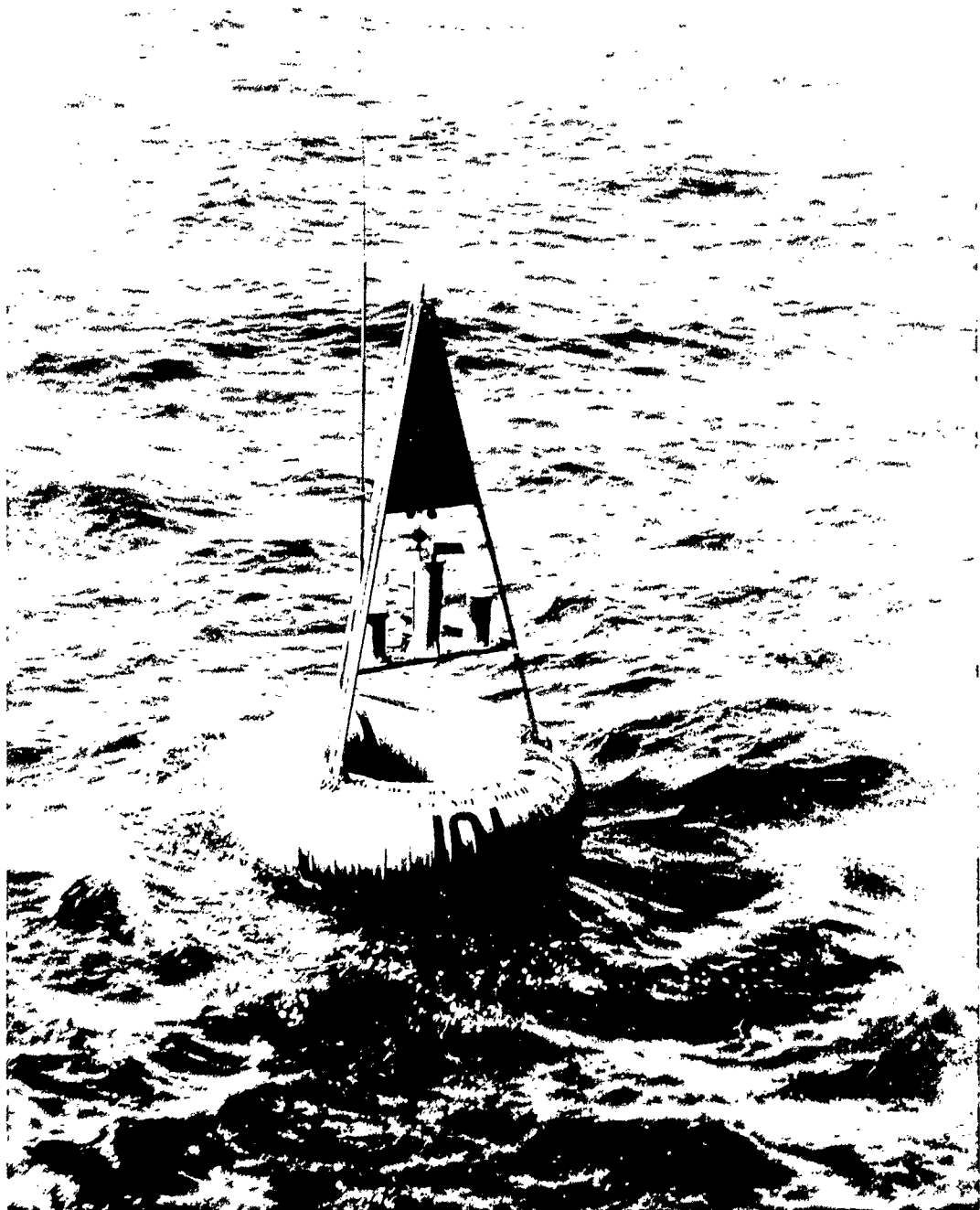FIGURE 2   CROSS SECTION OF THE LINE SHOWING THE DISTRIBUTION
OF INSTRUMENTS

2-METER CHAIN BRIDLE

6-METER CHAIN LEADER

50 METERS $\frac{9}{16}$" POLYPROPYLENE

CURRENT METER

$\frac{9}{16}$" POLYPROPYLENE IN 500-METER
LENGTHS-CURRENT METERS AS DESIRED

CURRENT METER

$\frac{9}{16}$" POLYPROPYLENE

6 METERS 1" PROPYLENE

WEAK LINK

CHAIN

ANCHOR
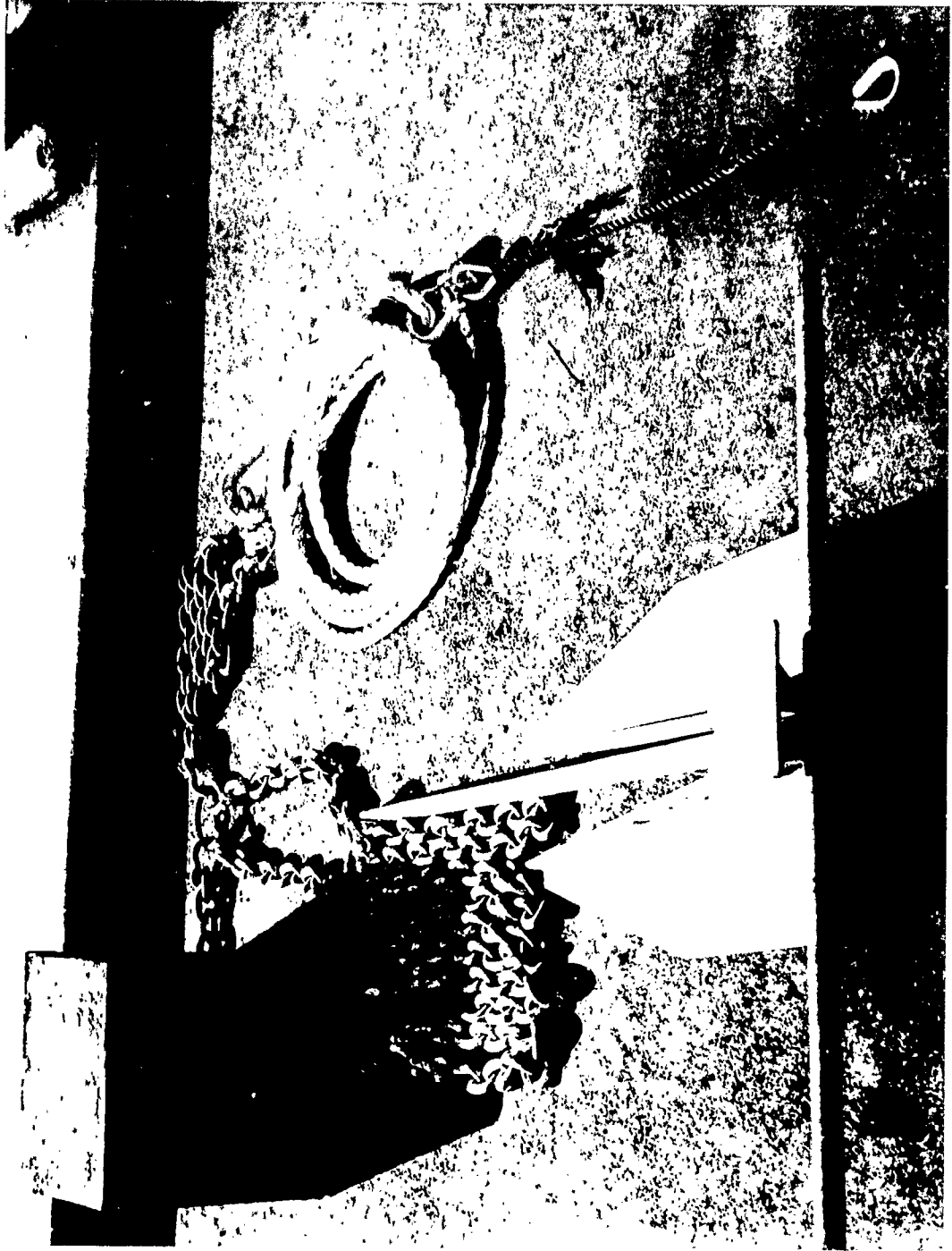
FIGURE 3   STATION

FIGURE 4   SURFACE FLOAT

FIGURE 5   GROUND TACKLE
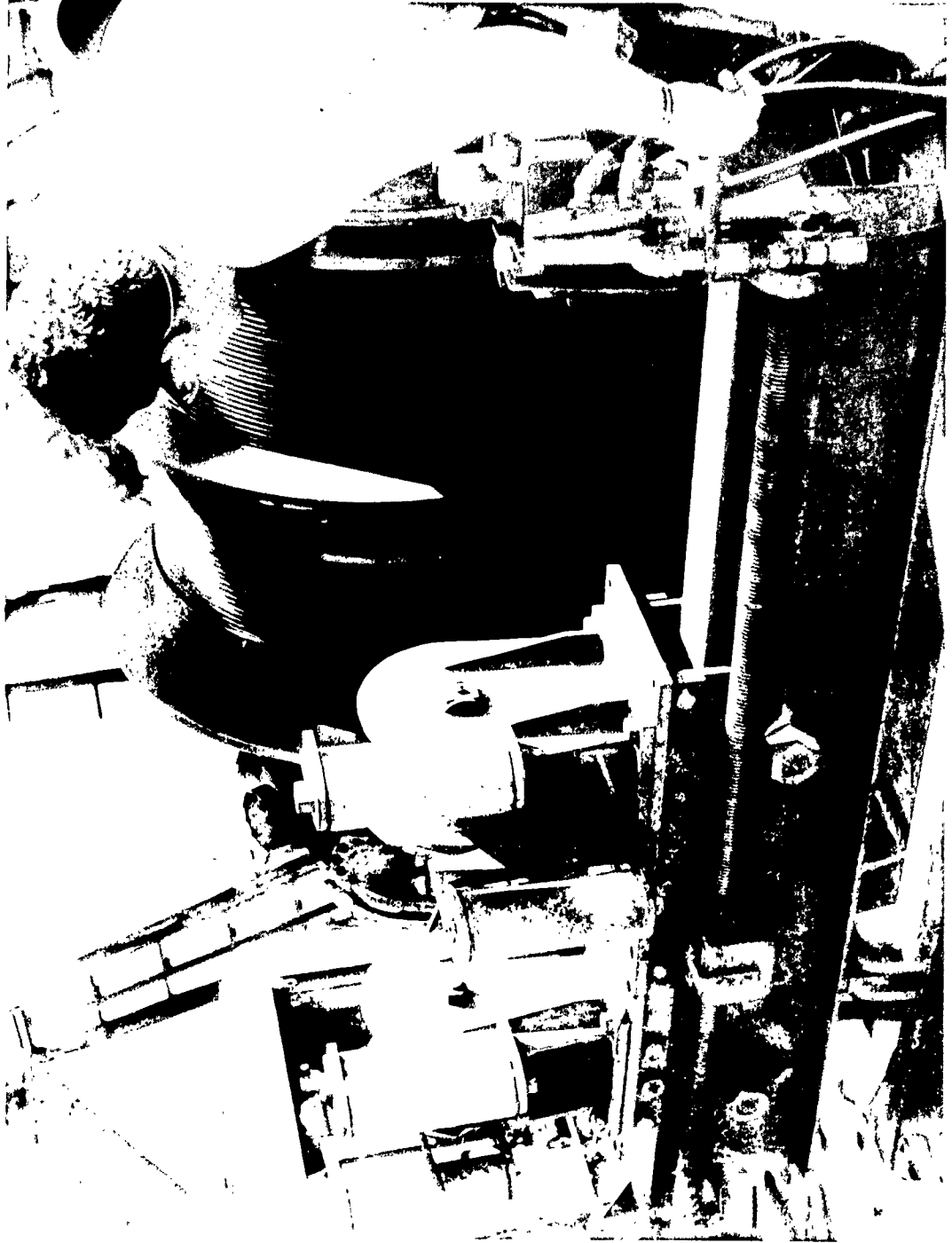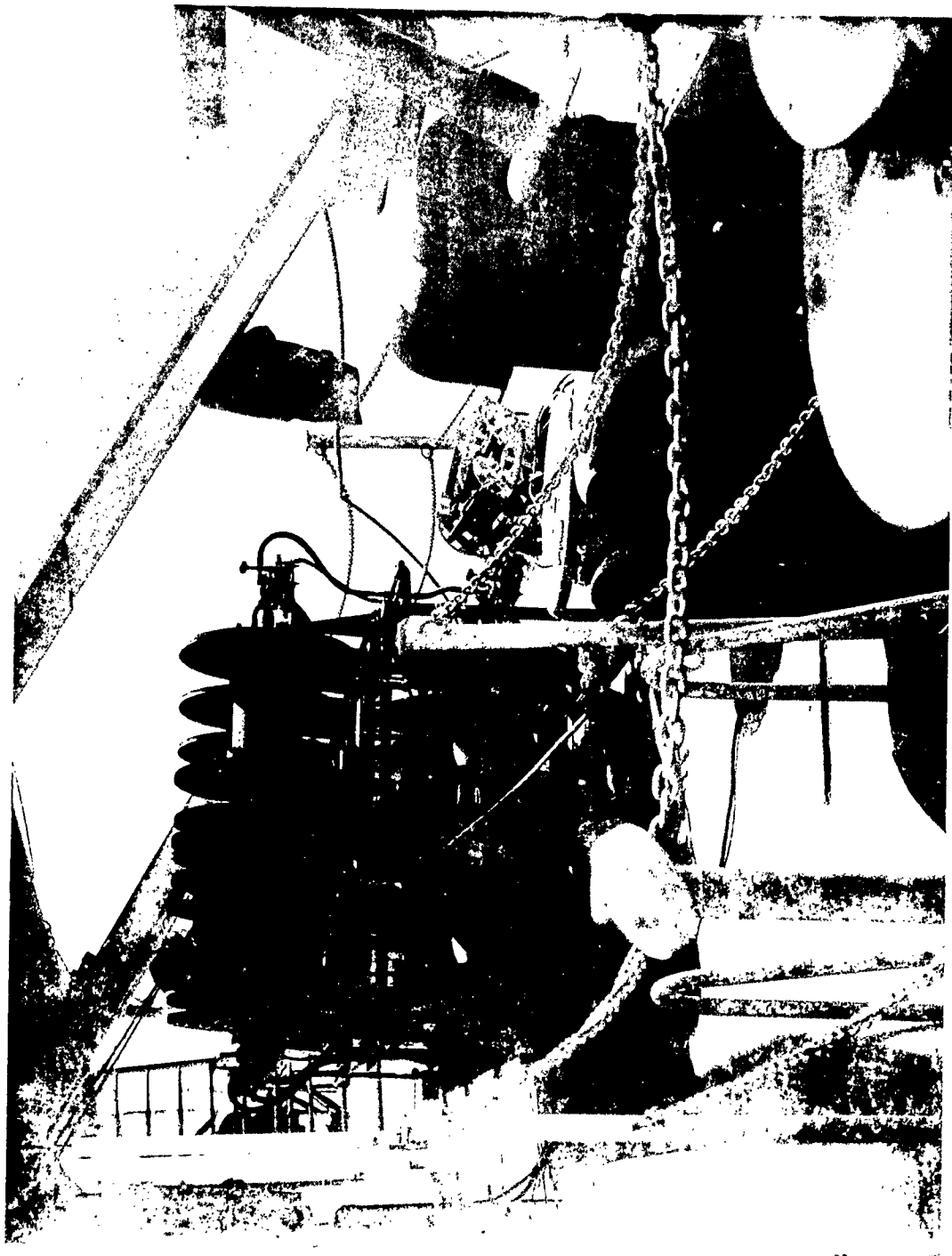
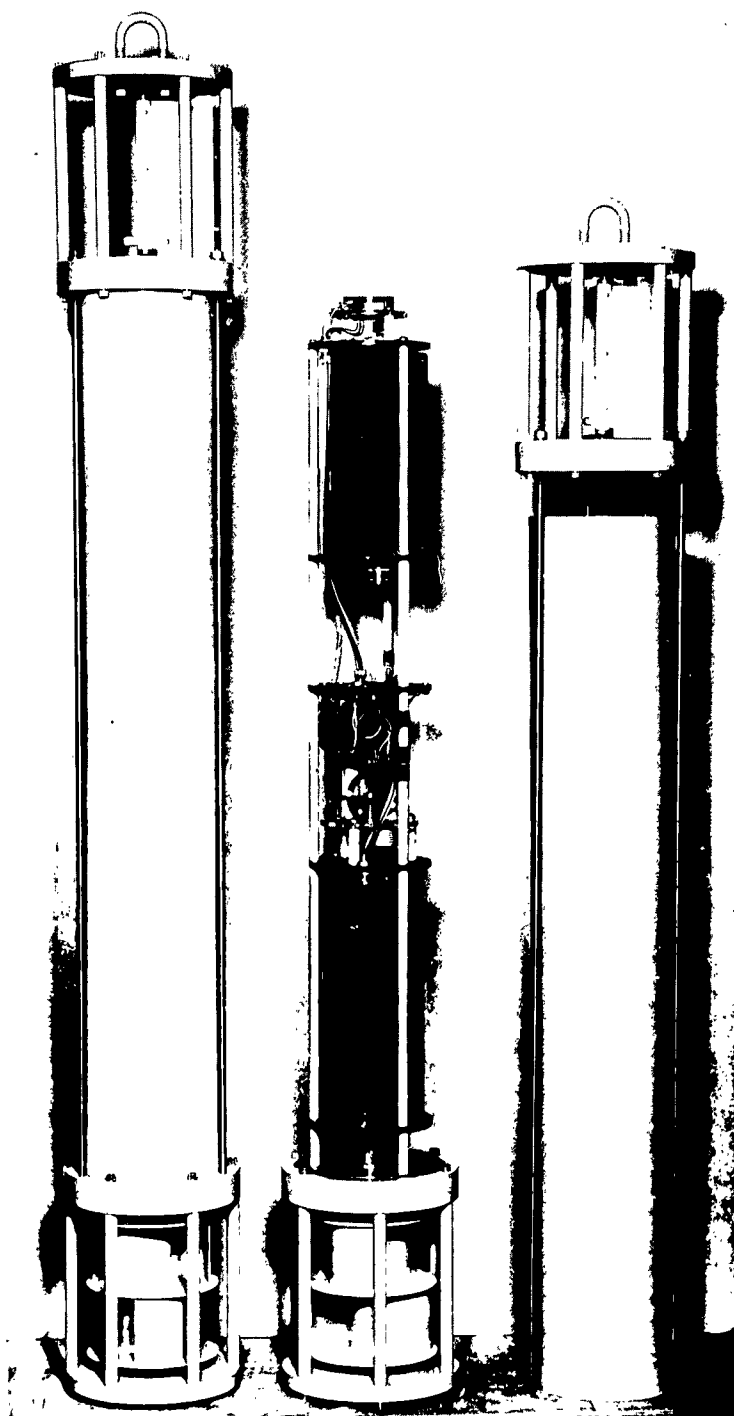FIGURE 6   PULLING WINCH

FIGURE 7   12-DRUM STORAGE WINCH
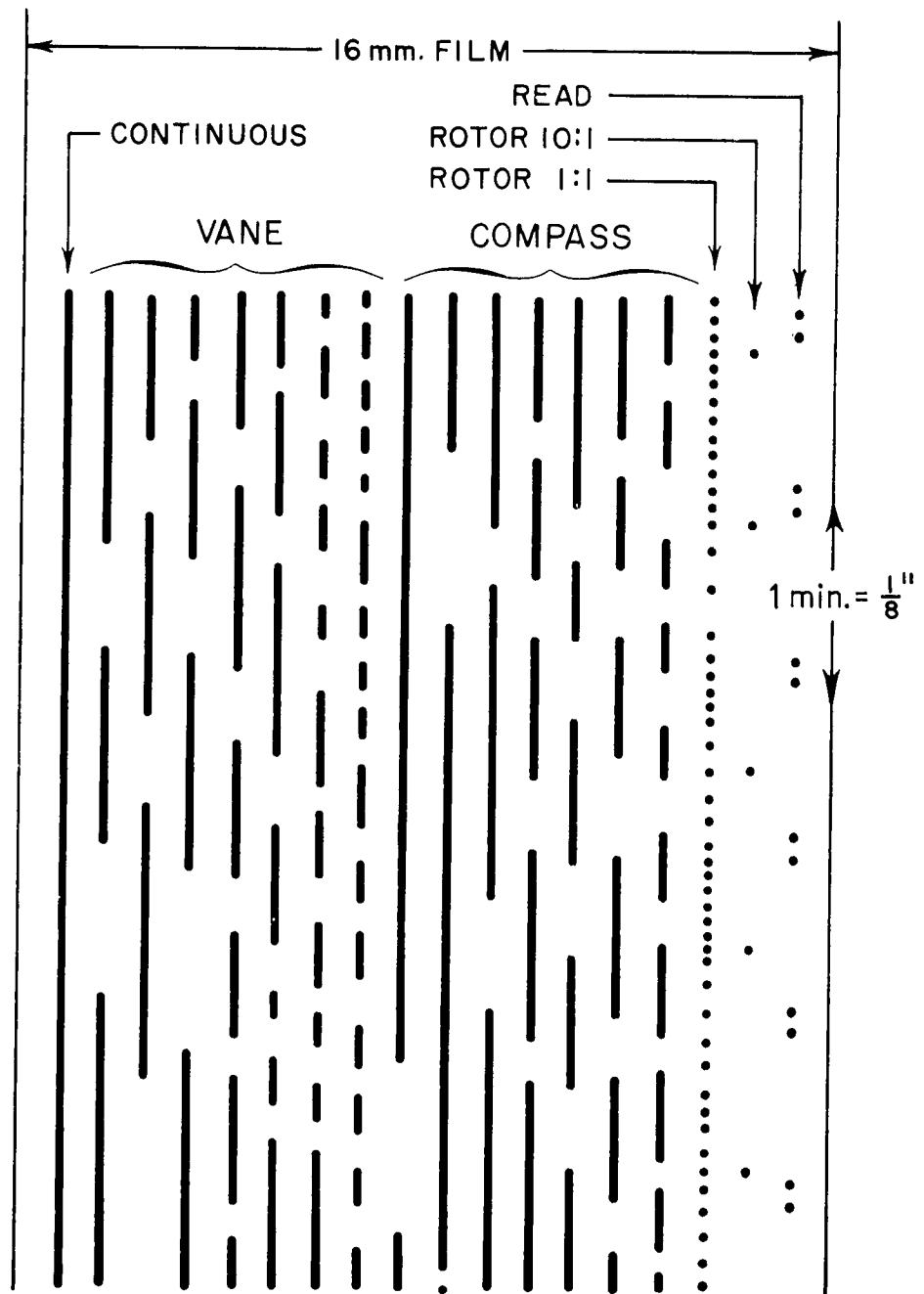
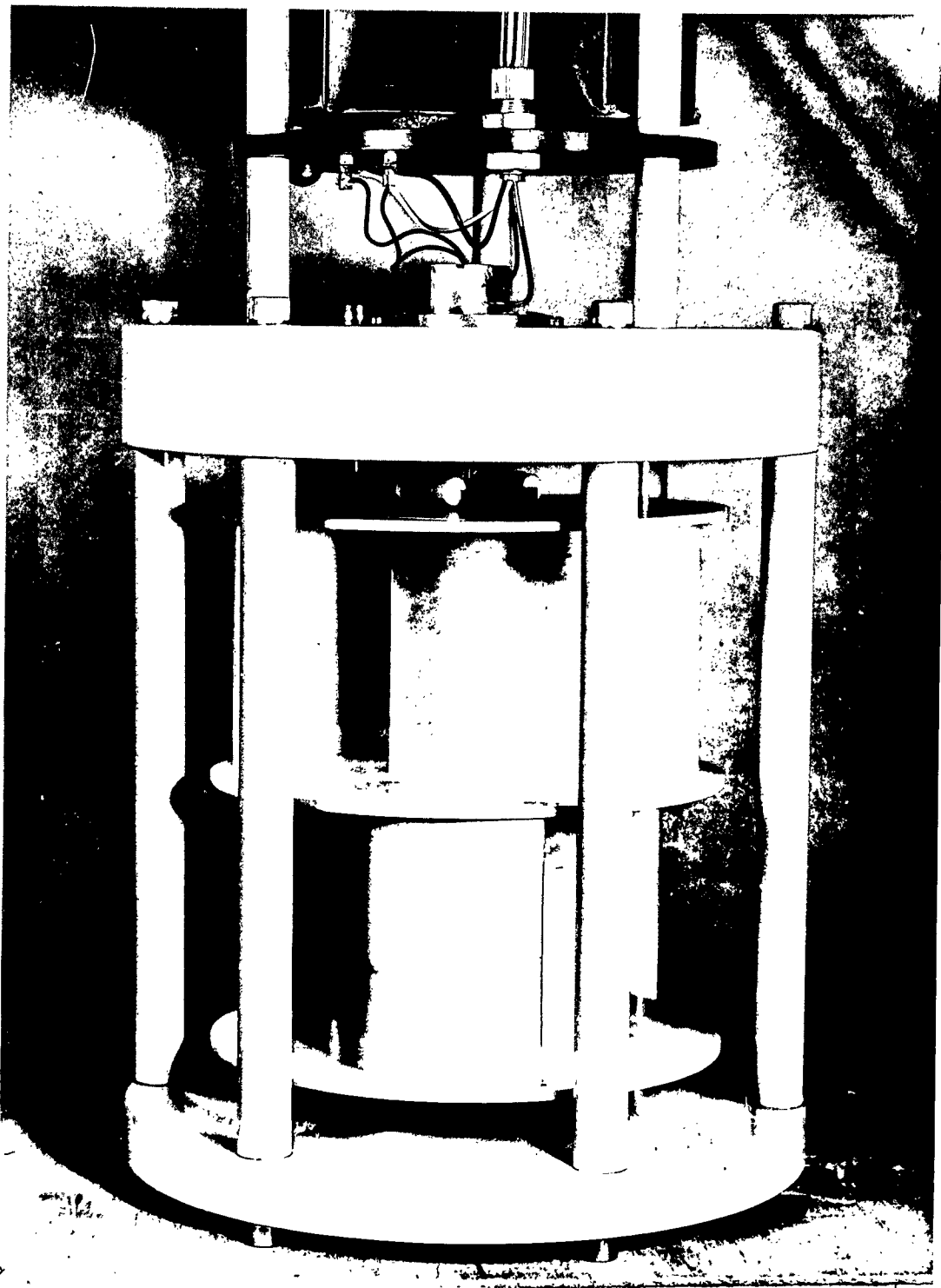FIGURE 8   CURRENT METER

FIGURE 9   CURRENT METER RECORD

FIGURE 10   ROTOR AND ROTOR FOLLOWER
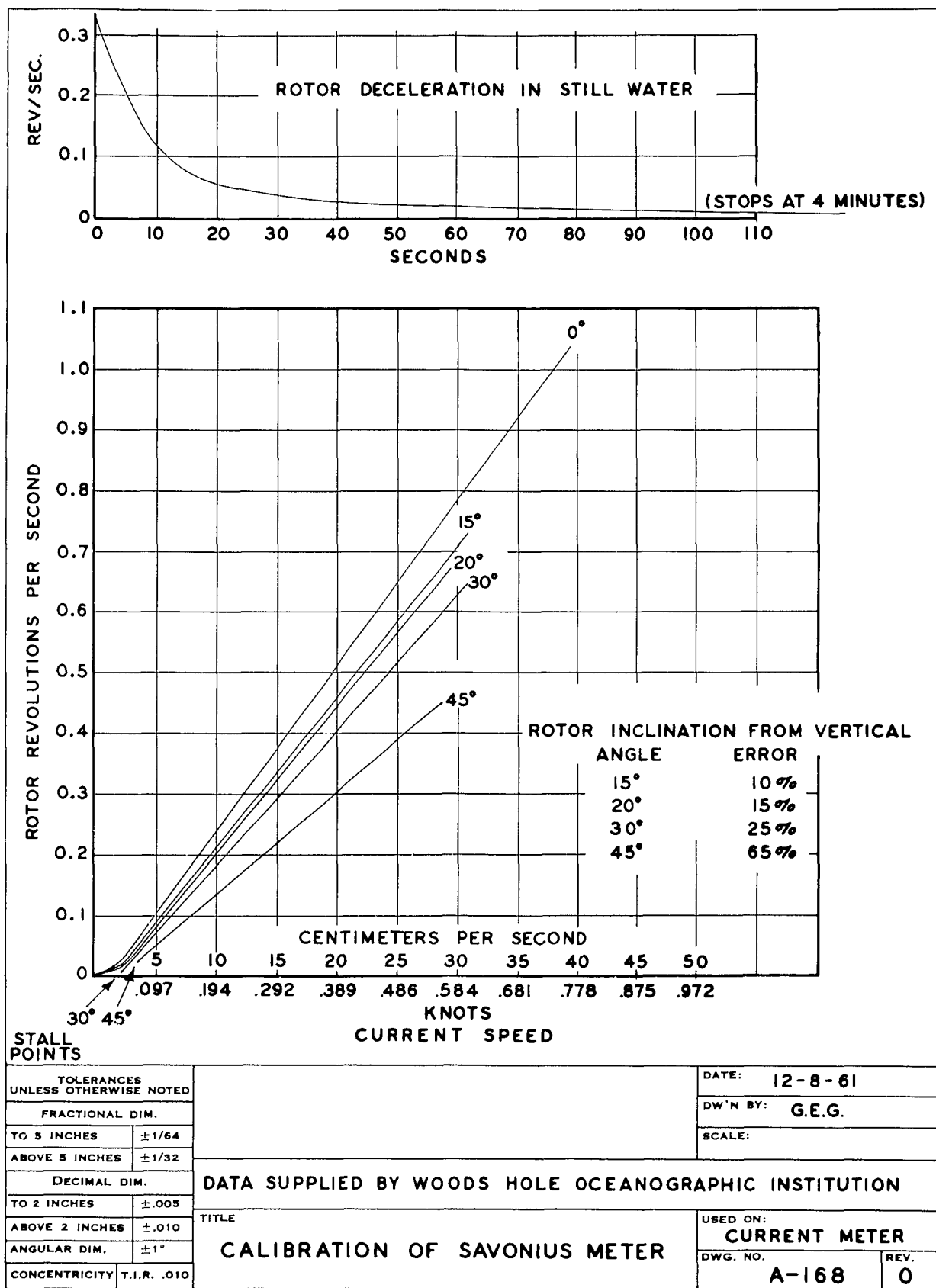
ROTOR DECELERATION IN STILL WATER

(STOPS AT 4 MINUTES)

ROTOR INCLINATION FROM VERTICAL

ANGLE	ERROR
15°	10 %
20°	15 %
30°	25 %
45°	65 %

CENTIMETERS PER SECOND

KNOTS

CURRENT SPEED

STALL POINTS

TOLERANCES UNLESS OTHERWISE NOTED		DATE: 12-8-61
FRACTIONAL DIM.		DW'N BY: G.E.G.
TO 5 INCHES	±1/64	SCALE:
ABOVE 5 INCHES	±1/32	
DECIMAL DIM.		DATA SUPPLIED BY WOODS HOLE OCEANOGRAPHIC INSTITUTION
TO 2 INCHES	±.005	
ABOVE 2 INCHES	±.010	TITLE · USED ON: CURRENT METER
ANGULAR DIM.	±1°	CALIBRATION OF SAVONIUS METER · DWG. NO. A-168 · REV. 0
CONCENTRICITY	T.I.R. .010	

FIGURE 11   ROTOR CALIBRATION CURVE

LIGHT CHOPPER - 10:1

SCALE: 2=1	APPROVED BY: A.S.F.	DRAWN BY G.E.G.
DATE: 6-24-61		REVISED 8-6-61
		DRAWING NUMBER A-78
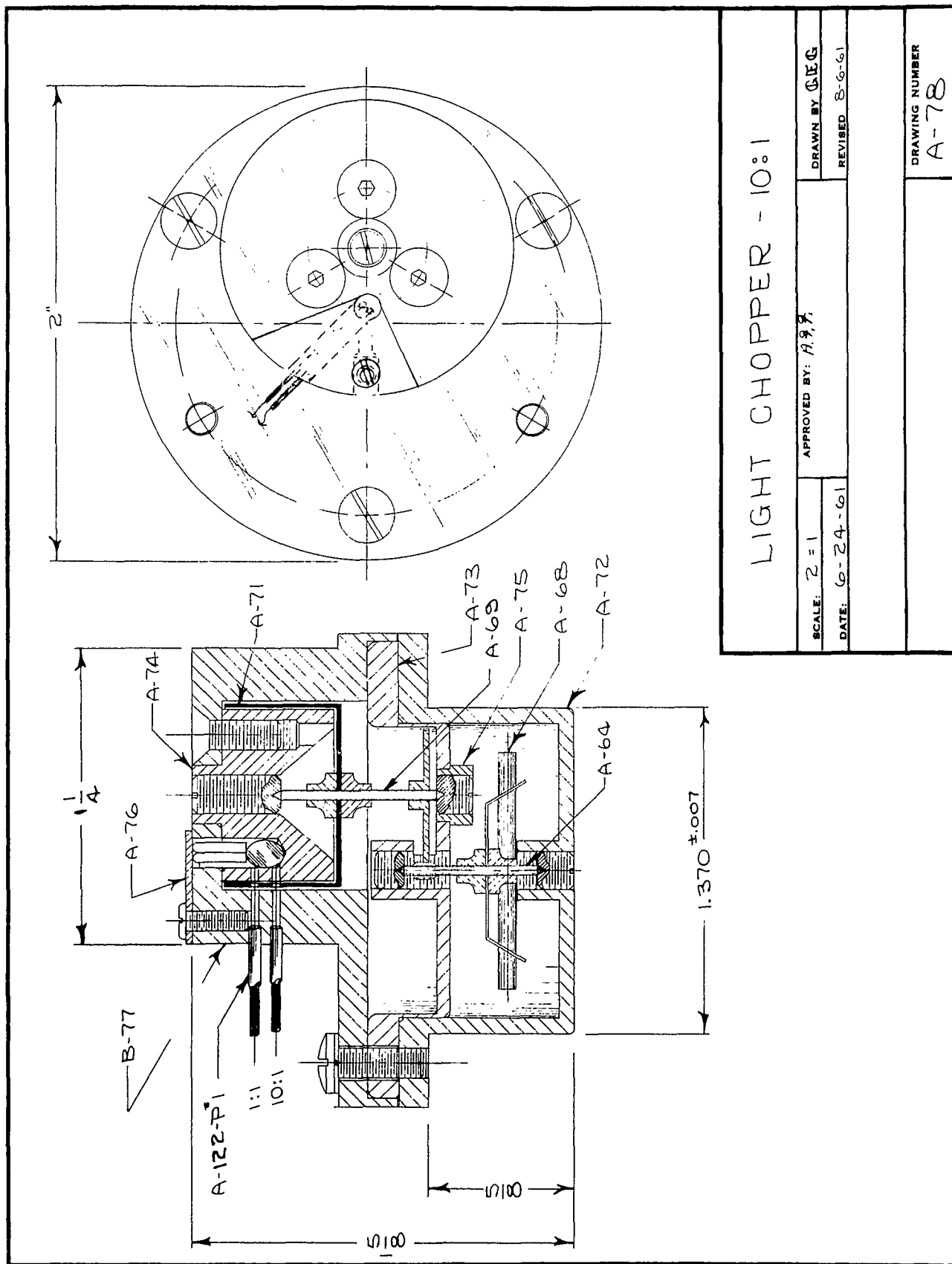
FIGURE 12   ROTOR FOLLOWER

PART NO.	DIM "L"	USED ON	
1	25 ±1/16	(2) ROTOR	(7) VANE
2	4 ±1/32	(2) REED PULSE	(7) COMPASS

P.V.C. #22 BLACK
TUBING .052 O.D. × .027 I.D.

OPTICAL FIBERS

#302 STAINLESS STEEL
TUBING .032 O.D. × .020 I.D.

$\frac{3}{8}$

$\frac{3}{8}$

L

POLISH ENDS

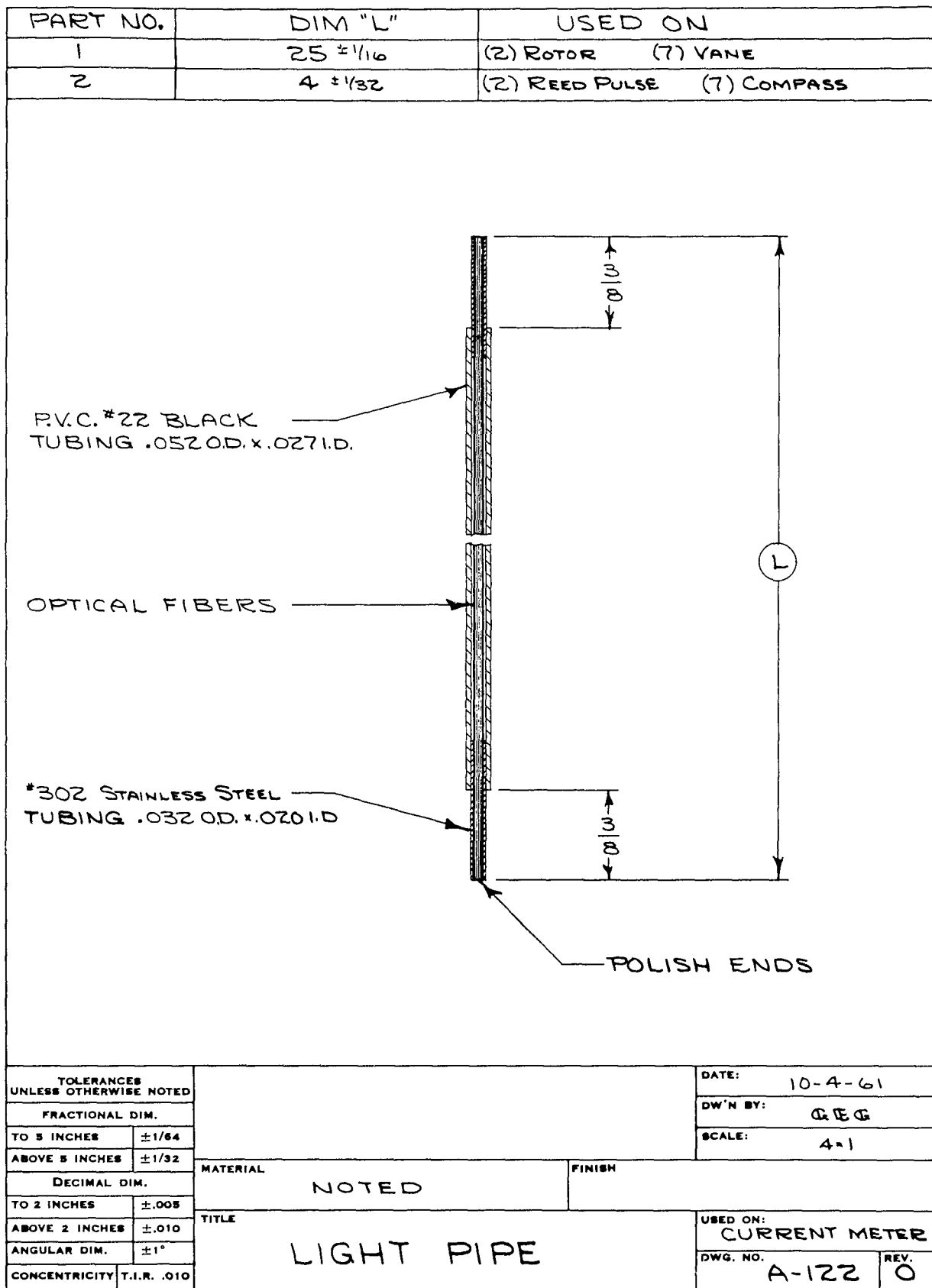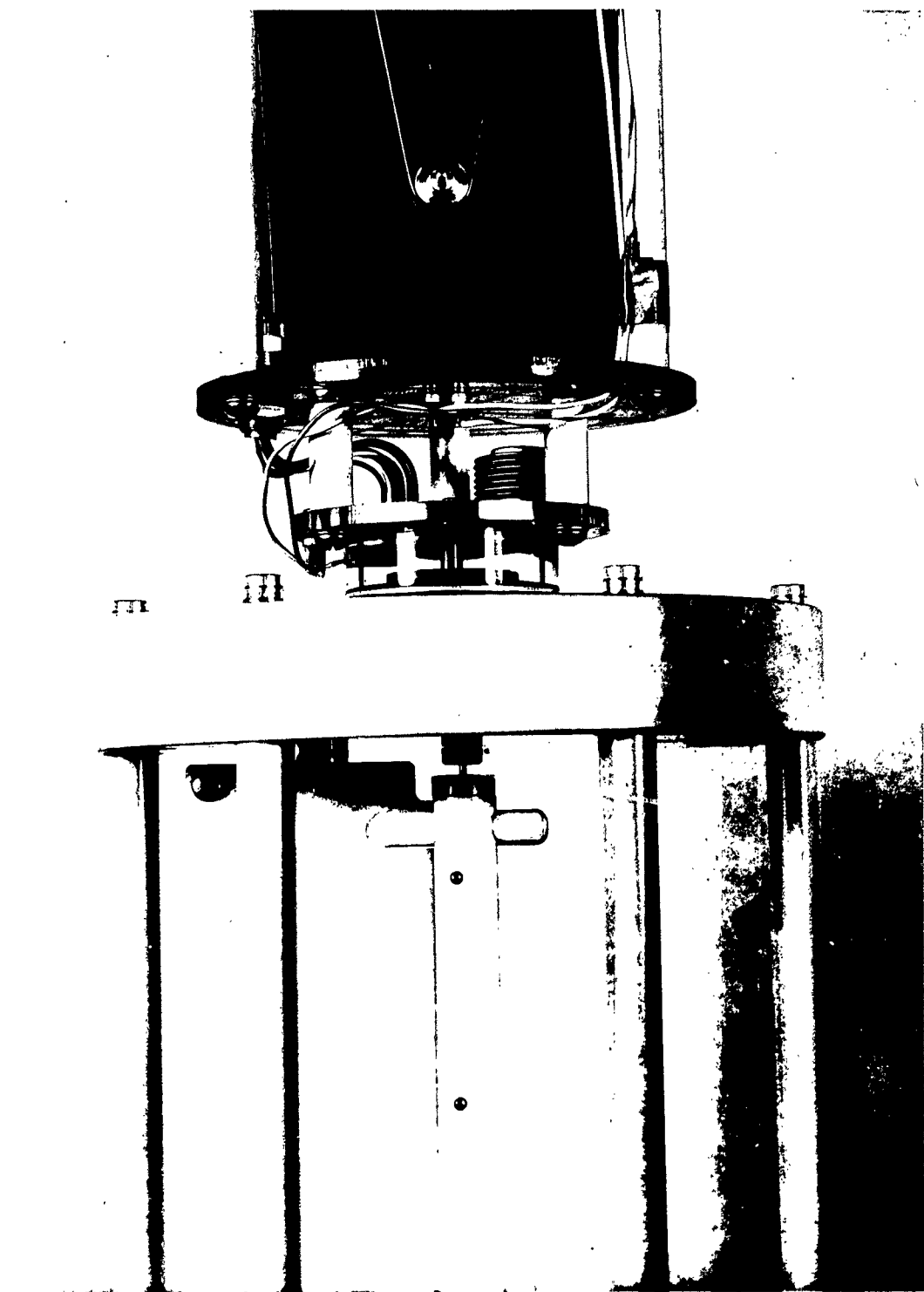| TOLERANCES UNLESS OTHERWISE NOTED		DATE: 10-4-61	
FRACTIONAL DIM.		DW'N BY: G.E.G	
TO 5 INCHES	±1/64	SCALE: 4×1	
ABOVE 5 INCHES	±1/32	MATERIAL NOTED	FINISH
DECIMAL DIM.			
TO 2 INCHES	±.005		
ABOVE 2 INCHES	±.010	TITLE LIGHT PIPE	USED ON: CURRENT METER
ANGULAR DIM.	±1°		DWG. NO. A-122	REV. 0
CONCENTRICITY	T.I.R. .010		

FIGURE 13   OPTICAL FIBER LIGHT PIPE
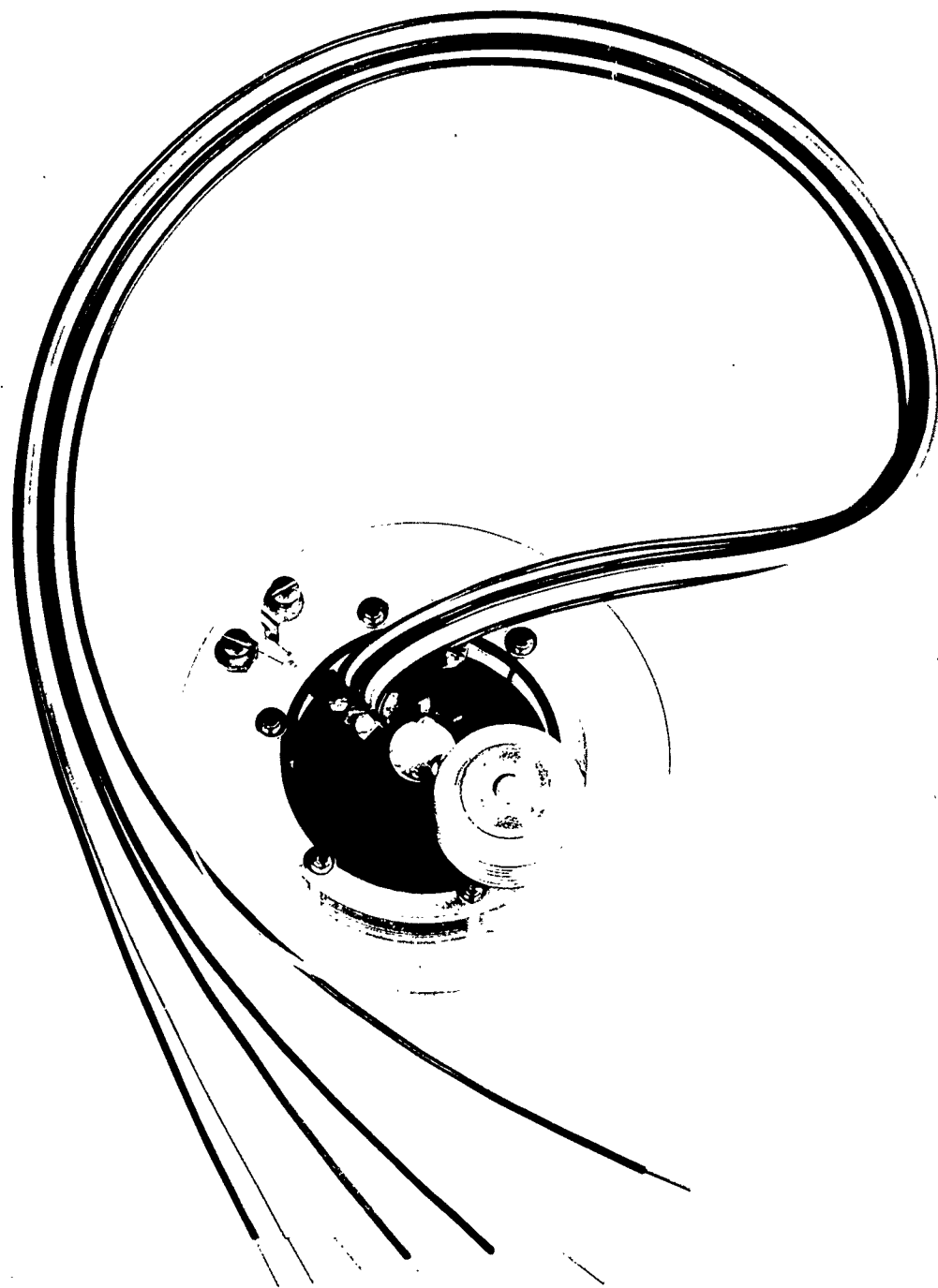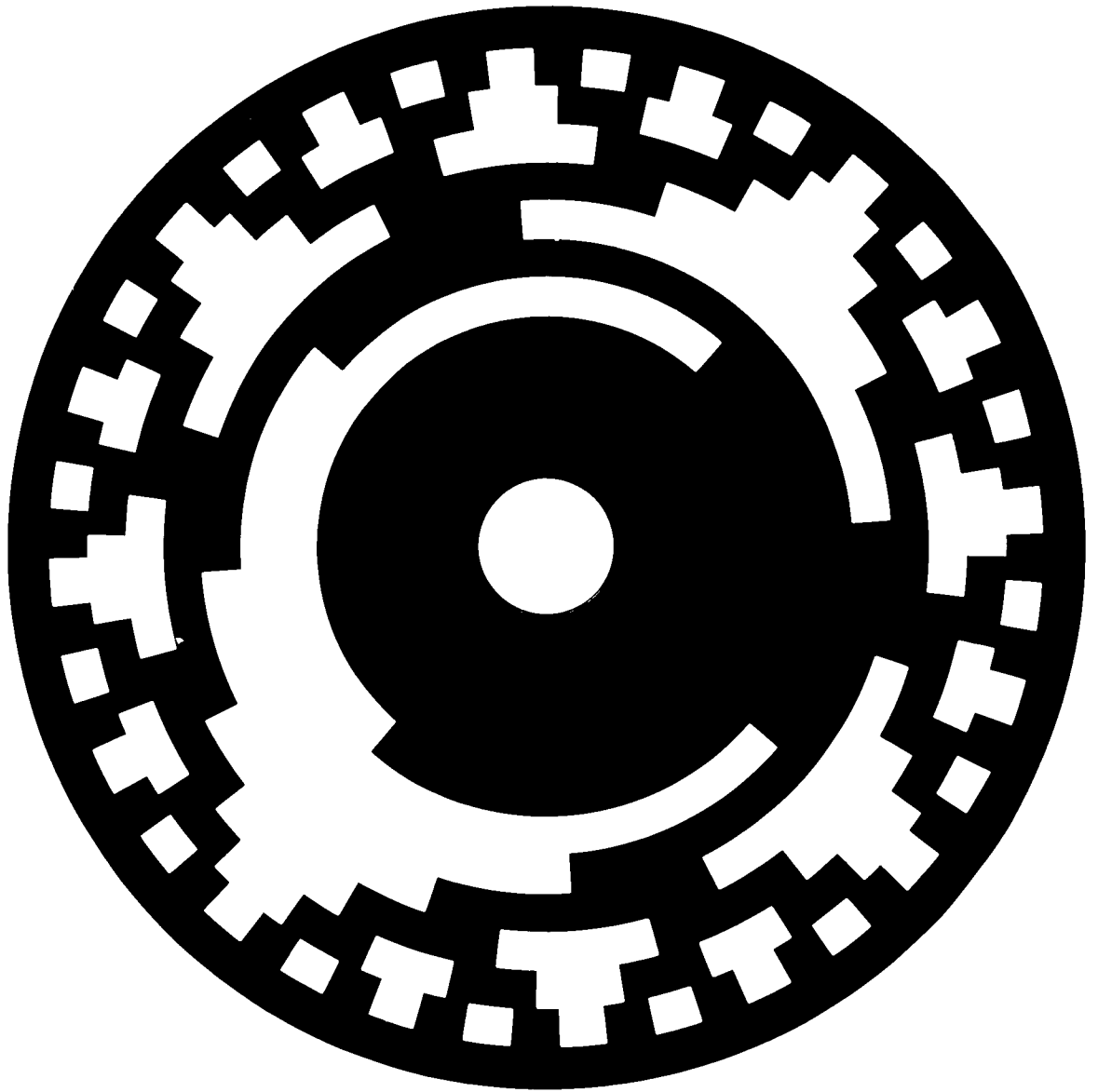
FIGURE 14   VANE

FIGURE 15   VANE FOLLOWER
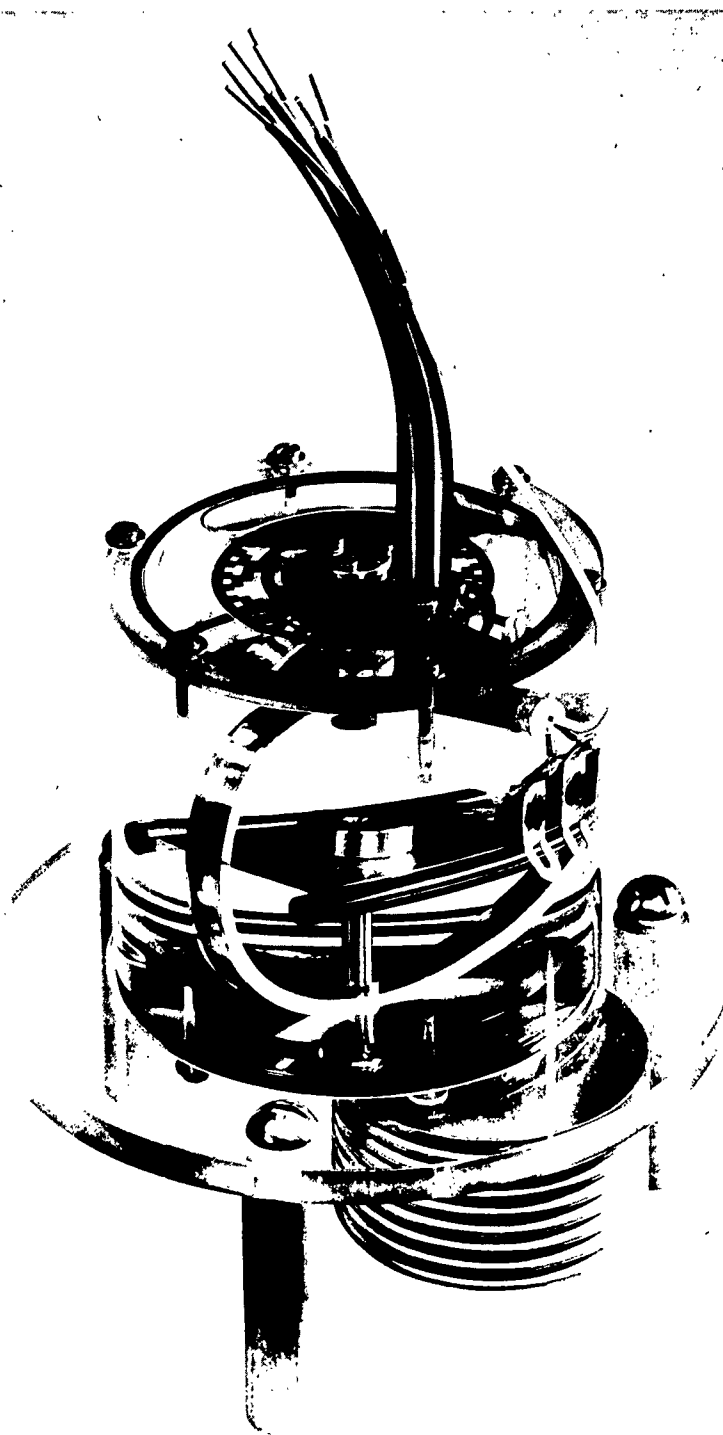
FIGURE 16   ENCODING DISC

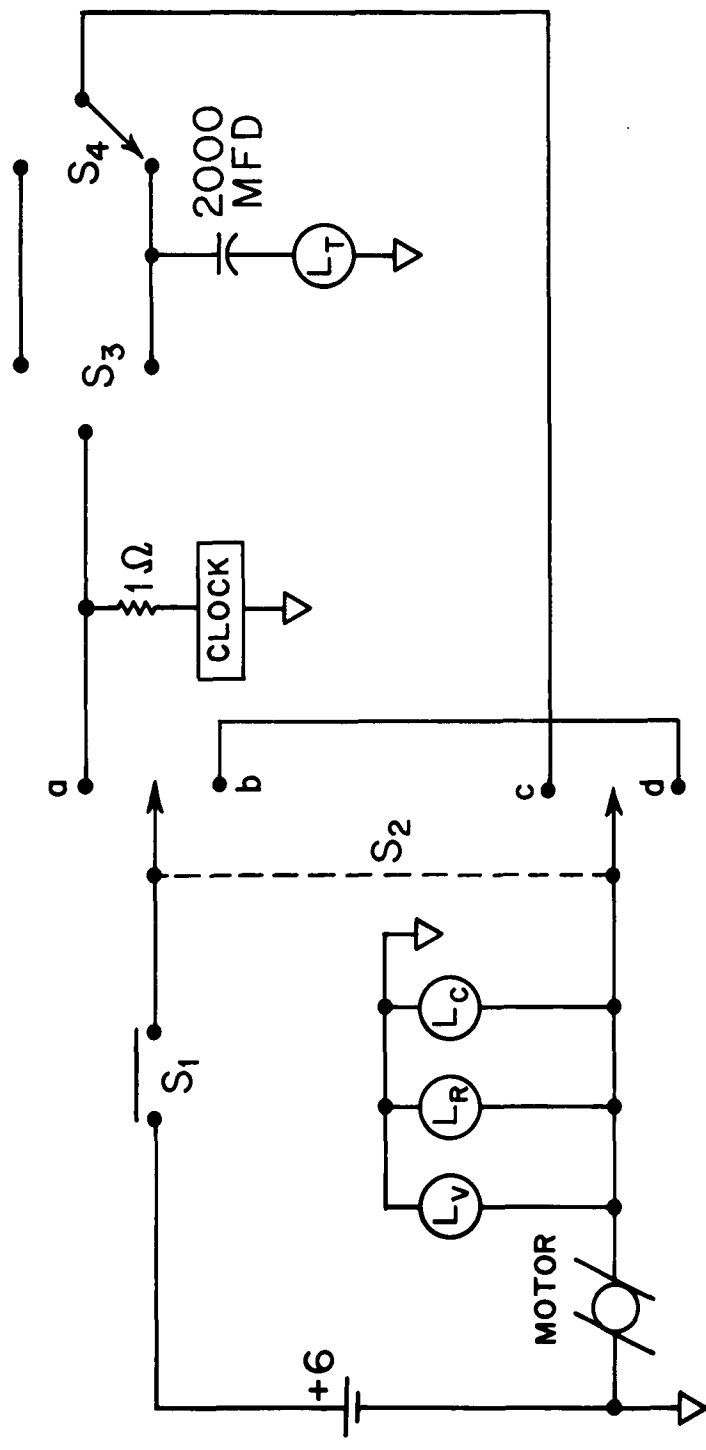FIGURE 17   COMPASS

FIGURE 18   CAMERA AND ITS FIELD OF VIEW

2000 MFD

CLOCK

1Ω

S₄

S₃

L_T

a

b

c

d

S₂

S₁

L_C

L_R

L_V

MOTOR

+6

S₁ = MERCURY SWITCH
S₂ = TOGGLE SWITCH
S₃ = CLOCK MICROSWITCH
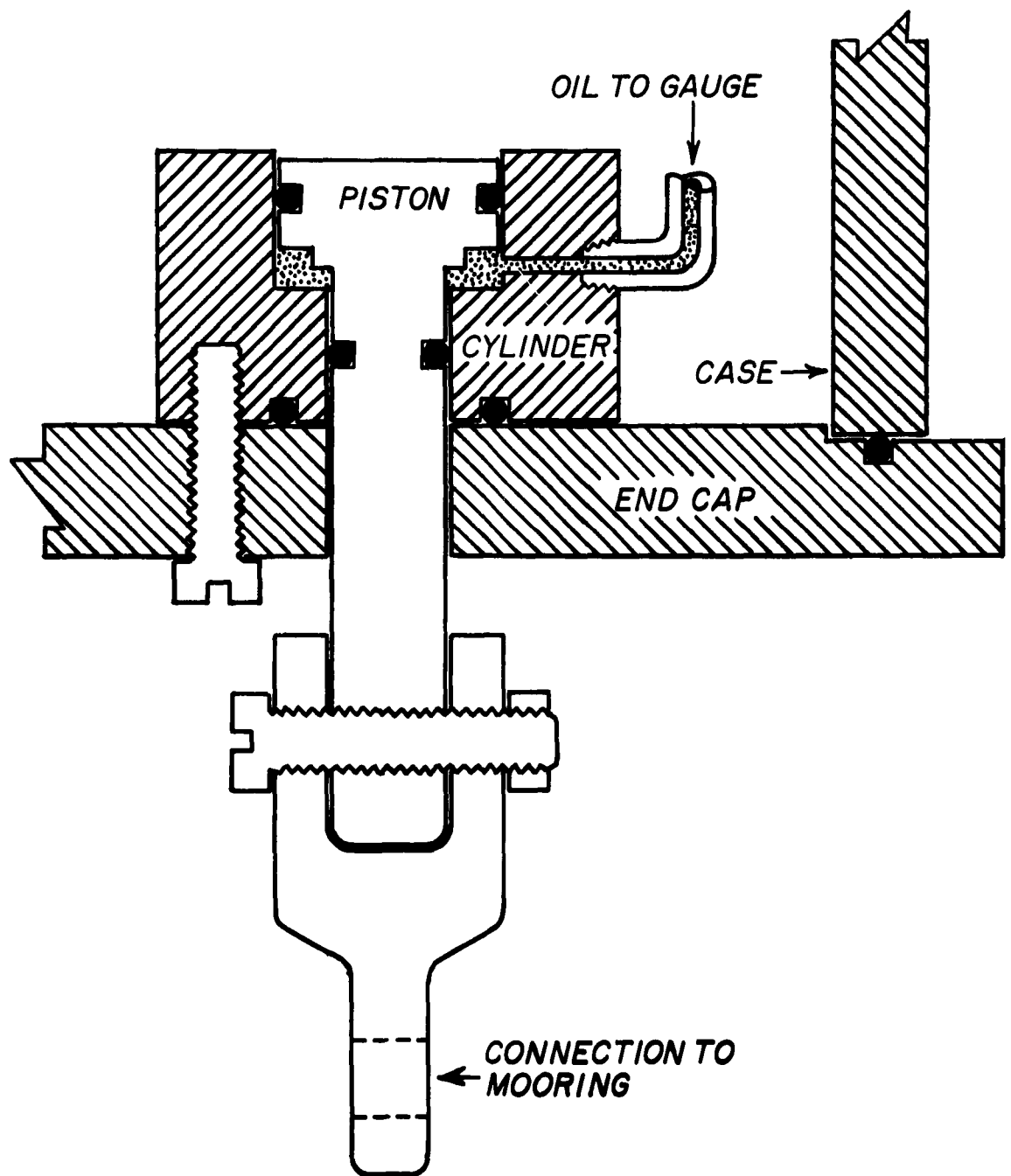S₄ = MOTOR MICROSWITCH

FIGURE 19   ELECTRICAL CIRCUIT

FIGURE 20   TENSION TO PRESSURE TRANSDUCER

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